SEWAGE WORKS JOURNAL

Vol. VII SEPTEMBER, 1935 No. 5

Special Articles

Thermophilic Digestion—Cleary

Oxygen Absorption by Activated Sludge—Kessler and Nichols

Oxygen Consumed and B.O.D.—Buswell and Bartsch

Activated Carbon Research—Rudolfs and Trubnick

Sludge Digestion in Pennsylvania—Kinsel

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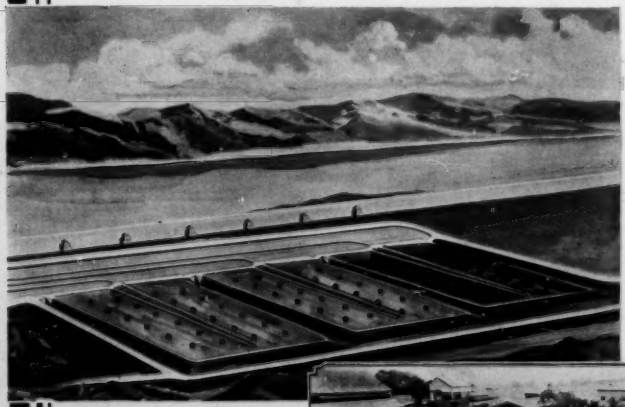

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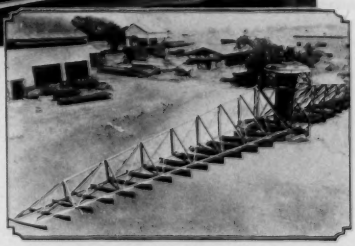

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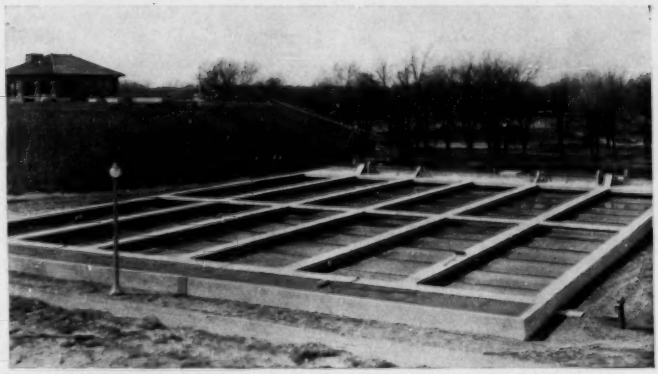

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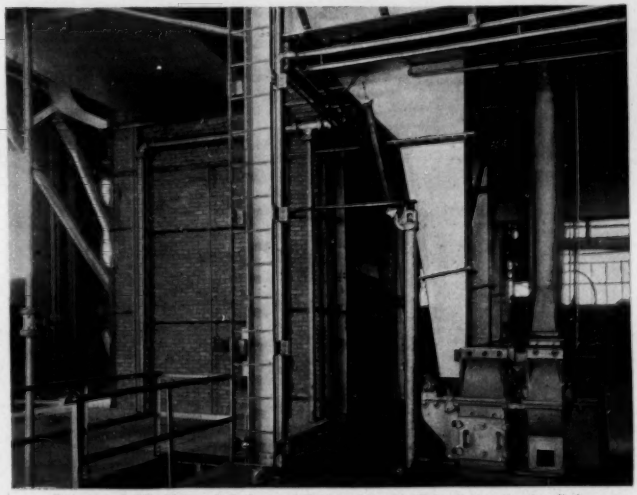

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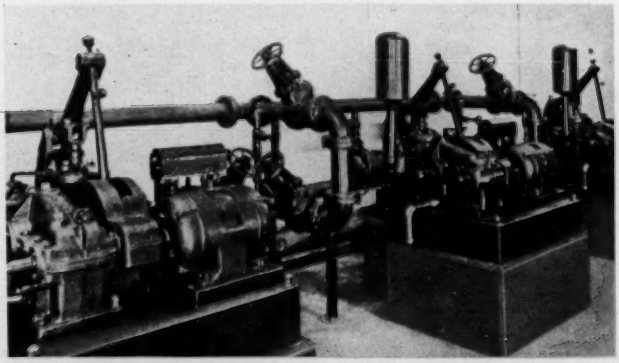

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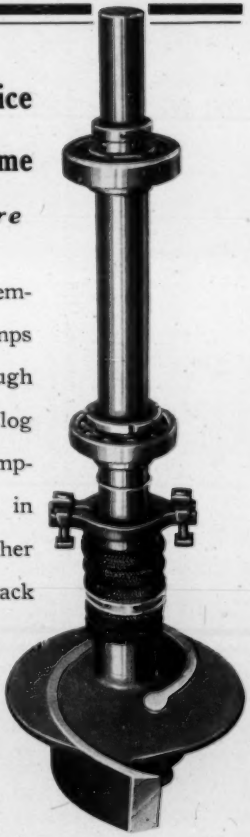

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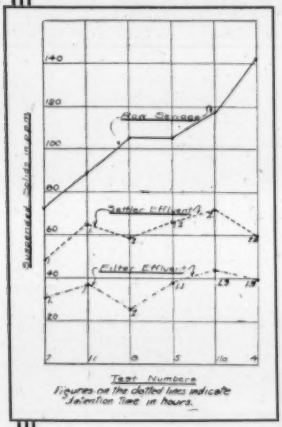

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Vol. VII September, 1935 No. 5

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Sewage Research

HIGH AND LOW TEMPERATURE DIGESTION EXPERIMENTS.* II. CONSECUTIVE DIGESTION

By Edward J. Cleary

Research Assistant, Division Water and Sewage Research, New Brunswick, N. J.

Results of experiments reported previously (5) conducted under thermophilic and mesophilic conditions in a pilot plant at the Freehold, N. J., Sewage Treatment Plant dealt primarily with operation difficulties, odors, gas production and drainability of sludge produced. No true, continuous, thermophilic conditions were maintained. The purpose of the present report is to present data dealing with a continuation of (1) mesophilic and thermophilic digestion, and (2) the combination of these two distinct types of digestion into a unit of successive stages designated as consecutive digestion. The question of the practicability of combining the two types of digestion to provide for rapid decomposition of organic matter with a production of an odorless, rapidly dewatering sludge, and the absence of troublesome supernatant liquid is of considerable interest. Operation of a semi-plant scale installation offers an opportunity to reach conclusions regarding the time of digestion, the rate of gas production and the destruction of volatile matter.

Description of Plant

A description of the plant was given in an earlier publication (1), but the stirring mechanism was changed as follows:

A ⅜-inch steel shaft extended through a packing gland and bearing in the center of the gas dome down into the tank where it was seated in a depression of the concrete base. Three paddles about 20 inches long, spaced at equal intervals, were welded on the shaft at right angles to the axis. The shaft of each stirrer was fitted with handles for manual turning, and pulleys which permitted mechanical operation by a motor connected to a worm gear and pulleys to produce 8½ r.p.m. A clock provided with a contact strip was so arranged that the stirring mechanism operated for ten minutes in every hour.

* Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J. Division Water and Sewage Research.

Method of Operation

One tank, properly seeded with thermophilic sludge, was kept at 130° F., while the second unit, seeded with mesophilic sludge, was kept at 80–84° F. Fresh solids from the preliminary settling tank were added daily to the thermophilic tank. Before making each addition, the supernatant liquor, equal in volume to the fresh solids added, was withdrawn and placed in the mesophilic tank. Mesophilic supernatant was wasted. Occasionally sludge drawn from the high temperature tank was placed in the low temperature unit.

Ash, moisture and pH determinations were made every week on composite samples of the materials added and drawn from each tank, and also on samples taken at one-foot intervals in the tank. Increases in daily additions were made every week until foaming resulted. Gas measurements were made automatically and recorded each day when measured quantities of new material were added.

Results of Tests

Thermophilic Tank

Digestion Schedule.—The operating data and results are shown in Fig. 1, while the condensed data given in Table I show that the time for digestion during December varied from 5.6 to 8.0 days. Considering the period as a whole the average time for digestion was 6.95 days. The April–May period reveals a digestion time from 4.5 to 3.6 days, with an average of 4.33 days. In this latter period the shorter digestion time resulted in a smaller percentage reduction of volatile matter and the gas per pound of volatile matter added was low. The tendency toward liquefaction was accentuated with the shorter digestion period. Calculations show that, in the first period, decomposition was almost the same as the rate of additions, whereas in the latter period the rate of decomposition was greater than the rate of additions. During this latter period a thick scum formed which was not typical of that found in mesophilic digestion tanks because it was quite moist, frothy and easily broken down. Foaming occurred once, accompanied by a violent ebullition of gas. The tank was rested for several days followed by a gradual decrease in the solids content of the scum layer, increased reduction of volatile matter, and greater gas production per pound of volatile matter added.

Reduction of Volatile Matter.—The reduction of volatile matter varied in general with the time of digestion. The correlation from the data at hand is shown in Fig. 2, and the relationship may be expressed by the formula, $53X - 5Y = 80$, where X is digestion time in days and Y is the per cent reduction in volatile matter. This straight-line varia-

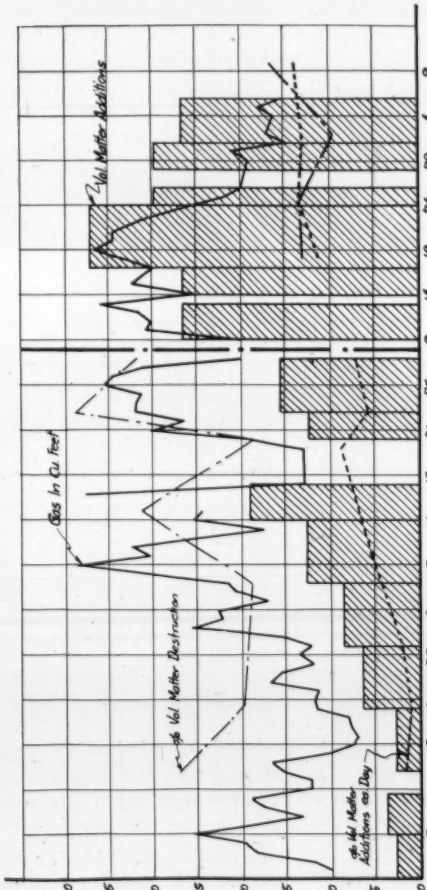

FIG. 1.—Operation data of thermophilic digestion tank.

TABLE I.—*Condensed Results, Operation of Thermophilic Tank*

Period Ending	Vol. Matter Added	Ave. Daily Vol. Matter Added	Vol. Matter Initial	Vol. Matter Added Daily	Dig. Time	Vol. Matter Destroyed	Vol. Matter Destroyed	Total Gas	Gas/Lb. Vol. Mat. Added	Gas/Lb. Vol. Mat. Destroyed
	Lb.	Lb.	Lb.	Per Ct.	Days	Lb.	Per Ct.	Cu. Ft.	Cu. Ft.	Cu. Ft.
Nov. 12	3.9	0.8	22.8	3.5	28.5	2.1	54.0	118.1	30.4	56.0
19	4.55	0.6	24.5	2.3	43.1	1.85	40.6	68.8	15.3	37.2
26	8.75	1.25	26.6	4.7	21.3	—	—	94.0	10.7	—
Dec. 3	12.0	1.72	14.9	8.7	11.5	4.5	37.5	144.6	12.0	32.1
10	17.7	2.53	20.5	12.6	8.0	11.1	62.8	198.0	11.2	17.9
18	15.2	3.80	21.5	17.8	5.6	5.8	38.2	145.0	9.55	25.0
21	7.5	2.50	21.1	11.7	8.6	5.8	77.5	75.4	10.0	12.9
28	21.6	3.10	20.9	14.8	6.8	13.7	63.4	218.4	10.1	16.0
Feb. 1	18.5	2.32	21.2	11.0	9.1	12.2	66.0	177.4	9.6	18.5
7	10.4	2.60	22.6	11.5	8.7	2.1	20.2	80.0	7.7?	38.2
Apr. 18	42.6	5.32	23.7	22.4	4.5	11.1	26.1	235.6	5.5	21.2
24	36.9	7.40	27.6	26.8	3.7	9.8	26.6	228.4	6.2	23.3
May 1	29.8	5.96	23.3	25.6	3.9	5.8	19.4	107.1	3.7	18.5
16	26.5	5.30	19.3	27.5	3.6	8.7	32.8	179.2	6.8	20.6

tion checks remarkably well with the summaries of the two one-month operating periods given in Table II. During the month of December, with an average digestion time of 6.95 days, the percentage reduction of volatile matter was 58.5; the graph gives 57.5. The April–May average digestion schedule of 4.33 days gave 26.2 per cent reduction in volatile matter; the graph in this instance shows 29.5 per cent.

Gas Production.—After December 3, 1934, when activities became stabilized, the gas per lb. of volatile matter added varied between 11.2 and 9.55 cu. ft. with an average of 10.3 cu. ft. for the month. In the April–May period when digestion was not proceeding smoothly, as evidenced by foaming and excessive scum formation, the quantities of gas varied between 3.72 and 6.78 cu. ft. with an average of 5.55 cu. ft. pH values of the supernatant liquid when plotted show a close correlation with the variation in gas production. Rudolfs (1) pointed out in connection with mesophilic digestion that "liquefaction" overbalances "mineralization" (gasification) at pH 7.2 but that the reverse is true at reactions of pH 7.6 and above. Apparently this same relation holds in thermophilic digestion and it is offered as an explanation of the low yields of gas per pound of volatile matter during the April–May period.

The gas produced per pound of volatile matter destroyed ranged from 25.0 to 12.9 cu. ft. with an average of 17.5 cu. ft. during the month of

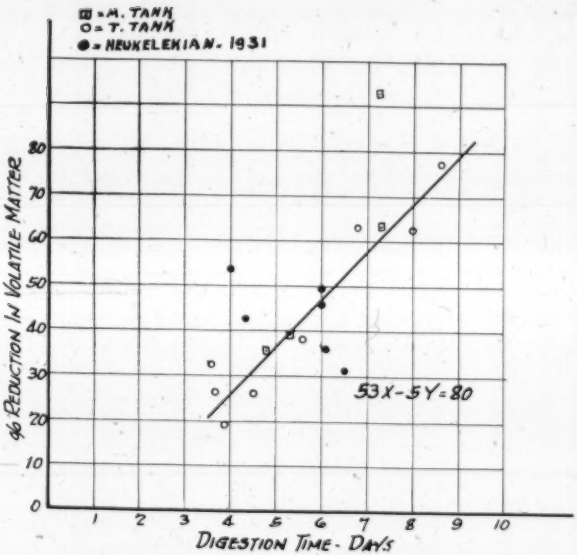

FIG. 2.—Correlation between reduction of volatile matter and time of digestion.

TABLE II.—*Summary of Two Periods of Operation*

Period	Thermophilic			Mesophilic		
	Dec.	Apr.–May	Total	Dec.	Apr.–May	Total
Volatile Matter, Initial, Lb.	20.5	23.7	—	18.6	28.0	—
Volatile Matter Added, Lb.	62.0	135.8	197.8	25.0	109.6	134.6
Ave. Daily Addition, Lb.	2.95	5.42	4.30	1.19	4.55	3.0
Volatile Matter Added Daily, %	14.4	23.1	18.8	6.4	16.5	11.5
Vol. Matter Destroyed, Lb.	36.4	35.4	71.8	14.95	60.6	75.5
Vol. Matter Destroyed, %	58.5	26.2	36.5	59.7	55.4	56.0
Gas, Cu. Ft.	636.8	750.3	1387.1	106.5	337.3	443.8
Gas/Lb. Vol. Matter Added, Cu. Ft.	10.3	5.55	7.02	4.25	3.08	3.30
Gas/Lb. V. M. Destroyed, Cu. Ft.	17.5	21.2	19.3	7.13	5.56	5.86
Digestion Schedule, Days	6.95	4.33	5.64	15.6	6.1	10.8

December. In the second period the variation was between 23.3 and 18.5 cu. ft., with an average of 19.3 cu. ft.

Effect of pH.—pH values were taken each week at one-foot intervals in the tank. The true index of the changes taking place was shown in the variation of the supernatant pH. During December the tank was not overloaded and the pH remained at 8.0 until the last week, when it dropped to 7.6. During the April–May period, with the digestion schedule almost constant and the tank overloaded, the pH values were never higher than 7.2 and as low as 5.8. Changes in pH can be directly correlated with changes in the gas per pound of volatile matter added, the rate of volatile matter destruction and the degree of liquefaction (Fig. 3). pH 7.2 seems to be the critical value above which decomposi-

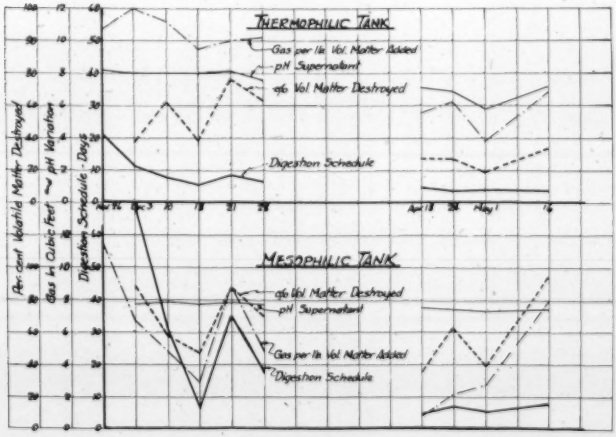

FIG. 3.—Comparison of digestion time, volatile matter destruction and gas production in thermophilic and mesophilic tanks.

tion advances at the same rate as additions are made and gasification holds predominance over liquefaction.

Effect of Stirring.—An appreciable aid in heat distribution was accomplished by operation of the stirring paddles, as observed from the graphical record on the Bristol temperature recording charts. The inked line on the chart showed the variation in temperature that normally occurs in a heating or cooling tank as broad and smooth undulations. After the stirring mechanism was installed, there appeared dis-

tinct jumps in the temperature line occurring once an hour (when stirring commenced) in which the temperature is shown to have moved upward into higher range by increments of approximately two degrees Fahrenheit. The heating coils were located two feet from the tank bottom and the thermometer element was three feet from the top—hence there was twelve inches of intervening space between the heat elements and the point of heat register. Since sludge is known to transfer heat very slowly and evenly, the abrupt advancing steps in temperature can only be due to stirring the hot mass from the bottom upward into the vicinity of the recording element.

Another fact was observed during a shut-down period. The heat was turned off because of trouble with the gas supply from the main plant digestion unit. Both experimental tanks were permitted to cool down and after six days a stabilization in tank temperature was effected, inasmuch as no further changes took place during the following six days. Although both tanks were identical in construction and insulation and they were both subjected to the same influences of outside temperature, the thermophilic tank contents stabilized themselves at a temperature of 60° F. and the mesophilic tank contents at 40° F. The mean outside temperature during this period fluctuated between 24° and 44° F. A check on the thermometers showed that they varied with each other less than one degree. A possible explanation is suggested by the work of Keefer and Kratz (2) who concluded from laboratory studies that digestion is exothermic during the early stages and endothermic in the later stages.

Mesophilic Tank

Digestion Schedule.—Condensed results and calculations are given in Table III. Digestion schedules varied from 6.75 to 35 days, averaging 15.6 days. Although this represents a variation of more than 80 per cent, the volatile matter destruction did not change more than 46 per cent. The long digestion periods were due to the fact that the load applied to the thermophilic tank was comparatively small and since the mesophilic tank received only the supernatant from the thermophilic unit the quantity of volatile matter added each day was small.

The April–May period was one of heavy loading for the thermophilic unit. The digestion period was quite constant, varying from 4.8 to 7.3 days, with an average of 6.1 days. The percentage volatile matter destruction and gas production, however, did not follow the changes in digestion schedule but showed continual improvement. (Fig. 3.)

Reduction of Volatile Matter.—Under the experimental conditions there appears to be no proportional relationship between the reduction of volatile matter and digestion time. During the long digestion periods

TABLE III.—*Condensed Results, Mesophilic Tank*

Period Ending	Total Vol. Mat. Added	Aver. Daily V.M. Added	V.M. Initial	V.M. Added Daily	Dig. Time	V.M. Destr.	V.M. Destr.	Tot. Gas	Gas/Lb. V.M. Added	Gas/Lb. V.M. Destr.
	Lb.	Lb.	Lb.	Per Ct.	Days	Lb.	Per Ct.	Cu. Ft.	Cu. Ft.	Cu. Ft.
Nov. 12	7.80	1.56	23.2	6.73	14.9	12.6	—	142.8	18.3	—
9	0.58	0.08	—	—	—	—	—	25.1	43.3	—
26	0.89	0.13	—	—	—	—	—	10.4	11.7	—
Dec. 3	1.91	0.27	19.2	1.93	7.0	1.7	89.0	12.6	6.7	7.4
10	4.15	0.59	18.6	3.20	31.2	2.45	59.0	19.5	4.7	7.95
18	10.99	2.74	18.5	14.80	6.75	5.25	47.8	32.0	2.92	6.1
21	1.92	0.64	22.2	2.88	35.0	1.70	88.5	17.0	8.85	10.0
28	7.95	1.15	20.1	5.72	17.5	5.55	70.0	38.6	4.86	6.95
Feb. 1	4.90	0.70	—	—	—	—	—	29.7	6.1	—
7	3.90	1.95	14.0	13.8	7.25	—	—	11.8	3.0	—
Apr. 18	29.60	4.22	20.8	20.8	4.8	10.5	35.6	24.5	0.83	2.3
24	31.40	4.50	32.8	13.7	7.3	20.0	63.6	68.7	2.20	3.41
May 1	28.00	5.60	29.2	19.2	5.2	11.0	39.3	81.2	2.86	7.38
16	20.60	4.12	29.7	13.8	7.25	19.1	93.0	162.9	7.90	8.50

the destruction of organic material showed little correlation with changes in the digestion schedule and with short digestion periods the reduction of volatile matter was equal if not better than that obtained with the long periods, considering the fact that highly acid material was introduced into the tank for a portion of the time. The best performance in the December period was 88.5 per cent reduction in 35 days, but in May at the termination of the experiment a reduction of 93 per cent was accomplished in 7.25 days.

Gas Production.—Material placed in the mesophilic tank had been deprived of much of its gas-producing elements during previous digestion under thermophilic conditions. In the December period the gas per pound of volatile matter added averaged 4.25 cu. ft., as against 10.3 cu. ft. in the thermophilic tank, a difference of almost 59 per cent. In the April–May period there was 44.5 per cent less gas produced per pound of volatile matter added.

The gas produced in the mesophilic tank per pound of volatile matter destroyed was 59.5 per cent less than the amount from the thermophilic tank, during December, and 74 per cent less during the April–May period, indicating that the gas-producing volatile matter had been vigorously depleted in the thermophilic unit.

Calculations show that long digestion periods were responsible for liquefaction rather than gasification. During the April–May period, with decidedly shorter periods of digestion, gasification occurred at all times but the tendency toward liquefaction occurred when the digestion exceeded seven days.

pH Changes.—pH values of the supernatant remained in the vicinity of 7.6, never advancing to more than 7.9 or dropping to a figure lower than 7.3. These pH values varied with the hydrogen-ion concentration of the material introduced from the thermophilic tank, so that the mesophilic tank contents served well as a buffering agent and the optimum alkaline conditions were maintained despite dosages of material that were decidedly acid.

Two-Stage Consecutive Digestion

Digestion Schedule.—Table IV contains a summary of the results of the combined operation.

It is believed that at the conclusion of the experiment on May 16, 1935, there was marked the average, in some respects, of what may be accomplished by combined successive digestion. Comparison may be made with results of December 18, 1934, when a short digestion time also occurred:

Results with Two Tanks Combined

	Dec. 18, 1934	May 16, 1935
Digestion Period	13.3 days	10.9 days
Volatile Matter Reduction	61.5%	59.0%
Gas per Lb. Vol. Matter Added	6.75 cu. ft.	7.28 cu. ft.
Gas per Lb. Vol. Matter Destroyed	16.0 " "	12.3 " "

Average results during the experimental period must be carefully analyzed. At the beginning, the tanks had insufficient time to be acclimatized to the new working conditions and in the middle of the experiment the overload and consequent foaming of the thermophilic tank caused such a drop in pH that biological conditions were temporarily upset.

The results seem to warrant the conclusion that, with twelve days of digestion, five in the thermophilic tank and seven in the mesophilic tank, adequate digestion of fresh solids will take place to a degree usually obtained only after thirty days with the mesophilic process alone.

Reduction of Volatile Matter.—To show the apportionment of the volatile matter destruction in the two tanks, the following tabulation is given.

	December Period	April–May Period	Summary Both Periods
Total Vol. Matter Added	62.0 lbs.	135.8 lbs.	197.8 lbs.
Vol. Matter Destroyed in T. Tank	36.4 "	35.4 "	71.8 "
Vol. Matter Destroyed in M. Tank	15.0 "	60.6 "	75.6 "
Total Vol. Matter Destroyed	51.4 "	96.0 "	147.4 "
% Total Vol. Matter Destroyed	82.0 %	71.0 %	74.6 %
Digestion Period (T. Tank)	6.95 days	4.33 days	

TABLE IV.—*Condensed Consecutive Data*

Period	Lb. Vol. Mat. Added			Lb. Vol. Mat. Destr.			Cu. Ft. Gas Produced			Days Digestion Schedule			% Vol. M. Destroyed	Gas/Lb. V.M. Added Cu. Ft.	Gas/Lb. V.M. Destroyed Cu. Ft.
	T.	M.	Both Tanks	T.	M.	Both Tanks	T.	M.	Both Tanks	T.	M.	Both Tanks			
Dec. 3.....	12.0	1.91	13.91	4.5	1.7	6.2	144.6	12.6	157.2	11.5	70	81.5	49.5	11.3	25.4
10.....	17.7	4.15	21.85	11.1	2.45	13.55	198.0	19.5	217.5	8.0	31.2	39.2	62.2	9.95	16.0
18.....	15.2	10.99	26.2	5.8	5.25	16.05	145.0	32.0	177.0	5.6	6.75	13.35	61.5	6.75	16.0
21.....	7.5	1.92	9.4	5.8	1.70	7.50	75.4	17.0	92.4	8.6	35.0	43.6	80.0	9.84	12.3
28.....	21.6	7.95	29.5	13.7	5.55	19.25	218.4	38.6	257.0	6.8	17.5	24.3	65.5	8.70	13.3
Apr. 18.....	42.6	29.6	72.2	11.1	10.5	21.6	235.8	24.5	260.1	4.5	4.8	9.3	30	3.60	12.0
24.....	36.9	31.4	68.3	9.8	20.0	29.8	228.4	68.7	297.1	3.7	7.3	11.0	43.5	4.35	10.0
May 1.....	29.8	28.0	57.8	5.8	11.0	16.8	107.1	81.2	188.3	3.9	5.2	9.1	29	3.26	11.2
16.....	26.5	20.6	47.1	8.7	19.1	27.8	179.2	152.9	342.1	3.6	7.25	10.85	59	7.28	12.3

A decrease in digestion period of 37.5 per cent was coupled with a decrease of 55 per cent in the percentage of volatile matter destroyed in the thermophilic tank, but the decrease in the total amount of volatile matter destroyed with both tanks was only 13.5 per cent. From this we might infer that a short thermophilic digestion with its consequent poor reduction in volatile matter does not materially affect the operation of the combined digestion unit. The April-May period summaries show that in 10.4 days with combined digestion it is reasonable to expect 71 per cent reduction of volatile matter, with 26.2 per cent of the reduction taking place in the thermophilic tank. From a general summary of all the data for the two periods studied it may be concluded that with a digestion schedule of 16.4 days, 75 per cent reduction of volatile matter was obtained, with 36.5 per cent of the reduction taking place in the thermophilic tank.

Gas Production.—Gas production from the two tanks was as follows:

	December	April–May	Summary
Total Vol. Matter Added	62.0 lbs.	135.8 lbs.	197.8 lbs.
Total Vol. Matter Destroyed	51.4 lbs.	96.0 lbs.	147.4 lbs.
Gas From T. Tanks	636.8 c.f.	750.3 c.f.	1387.1 c.f.
Gas From M. Tank	106.5 c.f.	337.3 c.f.	443.8 c.f.
Total Gas Produced	743.3 c.f.	1087.6 c.f.	1830.9 c.f.
% Produced in T. Tank	86%	69%	76%
Gas/Lb. Vol. Matter Added	12.0 c.f.	8.0 c.f.	9.3 c.f.
Gas/Lb. Vol. Matter Destroyed	14.5 c.f.	11.3 c.f.	12.5 c.f.
Available Gas Recovered *	91%	71%	78%

* Based on 16.0 cu. ft. of gas theoretically available in one pound of fresh solids decomposed.

The comparatively long digestion time of 22.5 days during December made possible the recovery of 91 per cent of the total gas theoretically available. The thermophilic tank accounted for only 26.2 per cent destruction of volatile matter with a 4.3 day schedule but it produced 69 per cent of all the gas. This means that a short thermophilic digestion is sufficient to produce almost three-quarters of the gas, leaving a balance of approximately 25 per cent to be given off during the secondary mesophilic digestion.

Discussion

The question may be raised as to the source of the ripe thermophilic sludge used in this experiment. The tank had been used for thermophilic digestion studies for approximately one year and before starting this research it was idle for less than three months in the summer season. By idle is meant that no heat was applied and no daily additions

were made. Heukelekian (3) showed that from the standpoint of seeding value it made little difference whether the sludge was stored at 122° F. or 68° F. and that storage up to three months did not cause deterioration of the seeding value. Nevertheless in order to make certain that thermophilic conditions were thoroughly established, a "breaking in" period of two months was used during which time small daily additions, gradually increased, were made.

With daily additions of fresh solids the average time for digestion during December, based upon the total amount of volatile matter in the tank, was 6.95 days, but the load limit of the tank was never reached. In the spring period the tank was purposely brought to an overloaded condition and the digestion period averaged 4.33 days. Between these narrow limits lies the optimum time necessary for digestion, which will be approximately five days. This means that not more than 20 per cent of the total amount of volatile matter in the tank can be added daily in the form of fresh solids. In proof of this assertion an examination of the April-May results reveals that when 22.4 per cent daily additions were made for one week, the tank functioned in good order but when this was increased to 26.8 per cent a foaming condition developed within a few hours; a slight reduction in the daily load alleviated the foaming but the pH was slow in rising. It appears certain that a daily load of more than 22 per cent fresh solids prepares the way for poor operating results.

Although the percentage reduction in volatile matter has been related to the digestion time in days, and expressed as the mathematical relation of $53X - 5Y = 80$, it is appreciated that no such dogmatic formulation would be applicable in all cases. This formula, however, does describe, within limits, an approximation of what can be expected and in a few instances it can be fitted to certain results obtained by Heukelekian (4). It has been stated that a digestion schedule of five days would be necessary; during this time a reduction in volatile matter of 37 per cent can be anticipated. This is based upon the supposition that pH values will be maintained above 7.6, because there is definite evidence showing that low pH values are severely detrimental to volatile matter reduction. With a daily increment of 20 per cent, and maintenance of thermophilic temperature, there is every reason and experimental evidence to show that the proper reaction will be automatically maintained, since the biological balance remains undisturbed.

Perhaps the chief function of an initial stage of thermophilic digestion is the ability to produce large quantities of gas quickly through the rapid decomposition of volatile matter. It was shown that, of the total gas produced through successive digestion in two stages, an average of seventy-five per cent was derived from the thermophilic unit.

Maximum was 86 per cent and minimum 69 per cent, the latter during the April-May period when conditions were unfavorable for rapid digestion.

Although this experiment was not extended sufficiently to furnish evidence to corroborate diverse statements in the literature regarding the value of stirring, it was clearly proven that slow stirring at regular intervals did provide a means for thorough heat distribution throughout the tank contents. Good heat distribution, particularly in the region of active digestion, is most important in promoting those factors which are favorable to maintenance of a biological balance and consequent rapid organic decomposition with attendant gas production. The stirring mechanism, composed of three horizontal paddles spaced equidistant on a vertical shaft, was originally intended to provide for intimate mixing of fresh solids with ripe sludge and to break up scum. Evaluation of the former function could not be made because of insufficient data; although the top paddle, which laid in the scum, did not prove an effective means for dispersing scum, it did aid in submerging this material. Periodic submersion helped in keeping the scum porous so that the gas could break through. Each time the stirrer was operated an immediate pickup was noted in the rate of gas production, which no doubt resulted from the release of entrained gases in the scum layer.

The data at hand indicate that the gas-producing volatile matter was the material most vigorously attacked in the thermophilic unit while the mesophilic tank performed the function of digesting the more resistant matter. Thus it acted in the rôle of a conditioner of sludge, reducing its total volatile matter to even a greater degree than is normally obtained with thirty-day single stage mesophilic digestion. The resultant ripe sludge proved to be equal if not superior in those highly desirable qualities of good drainability and lack of odor.

On a volatile matter basis the daily load handled most efficiently by the tank was 14 per cent of the amount of ripe sludge present. This is more than three times the load that can be safely applied to the ordinary single-stage mesophilic digestion unit and concretely expresses an advantage afforded through pre-thermophilic treatment.

One of the most obvious effects noted through secondary mesophilic digestion was the production of a clear supernatant. High temperature digestion is responsible for rapid evolution of gases with consequent disturbance of sludge, thus making the supernatant liquor high in solid content. When this material is placed into the low temperature mesophilic tank it is not only completely digested but the slow rate of action and low rate of ebullition of gas permit comparatively quiescent action so necessary for the establishment of a zone of satisfactory supernatant liquor.

Another point worthy of emphasis was the ability displayed by the mesophilic tank in resisting changes of pH. The introduction of highly acid sludges, which may result occasionally from a temporary upset in the first stage of treatment, should not seriously affect the completion of the digestion process, for it was demonstrated that buffering action in this second tank is pronounced. A sewage plant must be able to take care of a definite quantity of solids each day and should the digestion process be impaired for even a short time it becomes a serious problem to dispose of the highly putrescible sludge. One way to prepare for such contingencies is to provide over-capacity design but this is expensive insurance. The two-stage digestion with its flexible and adaptable secondary mesophilic tank provides a means to maintain economical design and simultaneously a high factor of safety.

Recognition has been accorded to stage-digestion processes as being preferable in many ways to single-tank digestion. It has been observed that pumping partly digested sludge from a primary tank stimulates the bacterial action which hastens ripening in a secondary tank; graphical analyses of curves of gas evolution from digesting sludge show that it is usual to have a period of high initial intensity followed by a decreasing rate of production. These facts suggest the feasibility of a consecutive digestion process in which most of the gas is liberated in a short initial period of digestion after which a second period is provided to "condition" and separate the sludge from the supernatant liquor. Among other things, consecutive digestion eliminates the possibility of raw sludge finding its way into the drying bed and it also prevents the formation of pockets of worked-out sludge which tend to silt up the digestion tank.

Previous work with Freehold sludge by Rudolfs and Miles (5) has established 16 cu. ft. of gas per pound of volatile matter destroyed as theoretically available. Using this as a basis for calculation only 78 per cent of the total available gas was recovered with the two stages of digestion, although the thermophilic unit alone gave approximately 100 per cent recovery from the material it digested. This clearly indicates that the prime function of the primary tank rests with its performance as a gas producer.

Practical Application

Fundamental studies on two-stage thermophilic-mesophilic consecutive sludge digestion indicate that it may hold promise for commercial development and application. The required digestion capacity could be reduced from 30 days to 12 days or a total of 60 per cent.

Design and operating factors that will greatly affect the successful utilization of the two-stage process must be thoughtfully considered. One of the most important of these is the method of heat distribution

and control. The usual practice of placing several coils of 1½-in. or 2-in. pipe around the inside periphery of the tank, through which hot water will circulate and thus transmit heat to the sludge mass, should prove adequate but the vertical location of these coils in the tank must be carefully chosen.

Incrustation and corrosion of the outer surface of the heating coils is frequently mentioned as an item of major importance in determining the practicability of heating by means of pipe coils. While this is important, particularly in connection with high temperature thermophilic digestion, there has been little evidence from the reports of separate digestion plants of any serious incrustation when the heating water temperature was below 140° F. After two years of operation at thermophilic temperatures the pilot unit at Freehold continues to function with the same efficiency as when it was first installed, yet the ingoing water temperature is quite high, because thermal circulation is depended upon for heating the sludge to 130° F. In order to keep the water temperature down to a point where baking of the sludge on the pipes would be inhibited the most desirable scheme is to provide a variable-speed circulating pump and thus secure equivalent heat transfer at lower initial water temperature. To insure uniform distribution of heat throughout the zone of digestion, there is a marked necessity for some method of slow stirring which will bring all of the sludge in contact with the heat coils. This fact was demonstrated with the semi-plant scale tanks, and other investigators have brought up this matter for attention by showing that sludge has a relatively low heat transfer coefficient from a heating coil because of its high viscosity. Tank insulation assumes an important rôle in heat control; Rudolfs and Miles (6) announced that the heat required to maintain the digestion tank at a given temperature varied directly as the temperature between the tank and its surrounding medium. Some ideas worthy of consideration in connection with tank insulation are: layers of ground cork blocks covered over with a ply roofing material; a secondary wall of hollow tile laid around the outside of the tank wall; or a 30-inch thickness of well-drained cinders. A drain around the bottom of the insulating medium will serve to conduct away any water that might collect and thus add to the efficiency of tank insulation against heat losses.

A potent factor affecting the economy of operation and one which should receive attention as a design feature is pre-concentration and decantation of fresh solids before their addition to the digestion tank. Several advantages are manifest: first, there will be a reduction in sludge volume to be digested and this will reflect itself in smaller required tank capacity; second, there will be less supernatant digestor liquor to be returned to the settling unit, where it is always a potential menace to

good plant operation; third, a large quantity of supernatant will be decanted before it enters the digestion tank, where it would not only absorb a large amount of heat while it is brought to the tank temperature but would also lose this heat faster than the sludge itself; fourth, concentrated seeded sludge has been found to digest better than dilute sludge. A possible disadvantage in placing a concentrated sludge in the digestion unit might be that this heavy mass would form in layers. Difficulty would arise for proper inoculation with ripe material, but a stirring mechanism, originally installed for heat distribution, could also serve as a mixer of the tank contents. It is recommended that a concentration tank be considered as a useful adjunct to the consecutive digestion process so arranged that not only will it provide for decantation of supernatant but it will also serve as a mixer wherein a certain amount of ripe sludge can be added with each batch of fresh solids. The purpose of this addition will be two-fold: it not only provides for inoculation with seed material but the buffering action of the ripe material will aid in maintaining an alkaline pH in the fresh solids which would otherwise septicize and become acid while they were concentrating.

In connection with the use of a concentration tank the possibility of pre-heating the fresh solids should not be overlooked. This could be accomplished by means of a grid or coil of hot water pipes placed in, or along the sides of, the concentrating unit. When it is recalled that the daily charges may be more than 20 per cent of the total tank contents it becomes apparent that should this material differ greatly in temperature from the thermophilic zone it will seriously retard the activity of digestion. Heat transmission occurs very slowly in the sludge mass and fresh solids from the sedimentation basins are quite cold, so that with large daily additions it is likely that considerable time would elapse before a uniform thermophilic temperature would be established throughout the entire tank contents. Pre-heating of the fresh solids would minimize this danger and in addition it would assist in the concentration process. Rudolfs (1) points out that at higher temperatures separation of water from solids is greater than at lower temperatures with the result that sludge becomes denser; this is the very effect accomplished by utilization of a concentration tank. At Manchester, England (7) a demonstration thermophilic sludge digestion plant has been in commission since January, 1931, and it is provided with an open concrete receiving tank 6 ft. 3 in. by 4 ft. 6 in. by 5 ft. deep, in which fresh solids are mixed with ripe sludge and the whole mass is pre-heated.

The advisability of a stirring mechanism cannot be too strongly stressed. It is not only of vital necessity to insure thorough heat distribution and to prevent the formation of any "layer" effects when a thickened sludge is added to the digestion tank, but with short digestion

periods it becomes essential that the fresh solids be quickly "seeded" without dependence upon natural admixture. At high temperatures the lighter materials in the sludge have a tendency to float and eventually a dense mat of scum is formed, which not only retards the digestion but makes a partly impenetrable mass through which the escape of gas is greatly hindered. This scum becomes fibrous and tough and if allowed to remain for any length of time it is difficult to disperse. Gentle stirring practised from the beginning of operations not only prevents the development of this scum but also serves to release the entrained gases at a uniform rate, with the consequent production of a dense ripe sludge.

Summary

Semi-plant scale studies based on a system of consecutive (two-stage) digestion, using a primary period of thermophilic digestion and a secondary period of mesophilic decomposition, show this to be a practical and economical scheme for sludge digestion.

The advantages over single-stage digestion processes which the results seem to warrant are:

1. Reduction of required digestion time to twelve days.
2. Greater destruction of organic matter.
3. Rate of gas production greatly accelerated. Five days of thermophilic digestion produces more than three-quarters of all the gas evolved.

Recommendations to obtain increased efficiency in the utilization of this process include: an adequate stirring device; concentration of fresh solids; pre-heating of fresh solids and inoculation with ripe sludge.

Acknowledgment

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DIGESTION OF HUMAN FECAL MATTER, WITH pH ADJUSTMENT BY AIR CONTROL (EXPERIMENTS WITH AND WITHOUT GARBAGE)

By S. Nishihara

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Sewage disposal works are becoming one of the principal undertakings of the municipalities in Japan. It will require many years, however, before cities and towns can complete these works satisfactorily, because the prevailing practice for ages in the Orient has been to utilize human fecal matter as fertilizer, and necessarily privies are of greater importance than flushing toilets in the unsewered districts. The demand for rational disposal, thereby changing this fecal matter to a harmless fertilizer, is therefore becoming a more and more important problem with the increasing population.

Under these conditions, the author has designed and constructed some excreta and urine disposal plants in the suburbs of Kyoto * and Tokio, adopting the activated sludge process with a view to use the plants as sewage disposal works later when needed. These plants are now in operation, with results as expected, but maintenance expenses, especially cost of electricity, are rather high compared with the return obtained from fertilizers. Moreover, the difficulty to find adequate means for garbage disposal brings about an additional burden to the municipality in such a humid climate as in Japan.

A desire to secure a more economical, simpler and adequate process for the disposal of the fecal matter, in conjunction with the garbage for the time being, and still have an easily changeable process with structures adaptable to a disposal plant whenever needed, has occupied the author's mind since 1925. Preliminary experiments for this purpose were conducted in 1931, but he failed to obtain satisfactory results.

In August, 1934, an experiment to digest human fecal matter with garbage by a process similar to sewage sludge digestion was again started, ending early in March, 1935. (Experiment I.) A confirmatory experiment was conducted from March to May, 1935. (Experiment II.)

The main purpose throughout these experiments was to secure pH adjustment in the separate digestion tank by air control, accompanied by proper seeding.

During preliminary experiments in 1931 the author noted that a few hours after the addition of fresh fecal matter, the air contained in the air-tight digester was consumed to such an extent that at times a vacuum

* See This Journal, 3, 656 (1931).

was created in the space above the contents. This fact led the author to realize that a greater amount of air is required for the digestion of organic substances by action of anaerobic bacteria than he had previously thought.

Following this observation, the experiments were planned to supply air to the fresh materials and ripe sludge by stirring the mixture in a pan outside the digester whenever additions were made. However, throughout all the experiments, only two stirrings, each of a few minutes duration, were made in the digester for the purpose of breaking up the scum. In order that the stirring process might not play an important role in digestion, the agitator "a" (see Fig. 1) was so constructed as to act only on the supernatant liquor and not on the entire contents.

I. Digestion of Fecal Matter with Garbage

Experiment I was carried out by the continuous incubation process at approximately 32° C. The experimental digester (Fig. 1) was 30 cm.

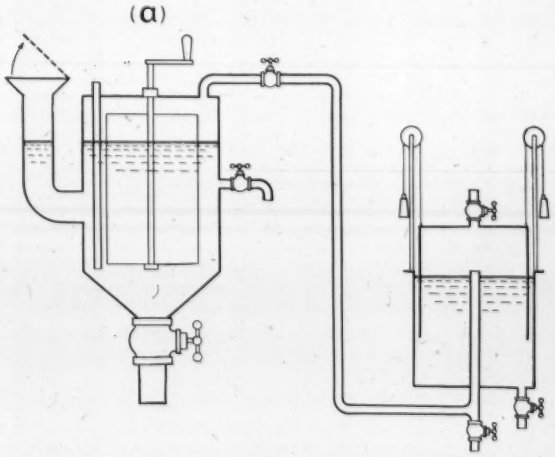

Fig. 1.—Experimental digester with gas holder.

in diameter and 50 cm. in total height, with a gas holder of 10-liter capacity.

Daily addition consisted of 500 cc. of human feces and urine, 55 gm. of garbage pulverized to ⅛-inch size, and 75 cc. of city water. This

quantity of excreta is equal to half the amount excreted per capita per day in a normal town in Japan, and the amount of water used for cleansing one in actual operation. At the start there were 25 liters of material in the digester, namely 5 liters of ripe sludge and 20 liters of supernatant liquor, which had been produced by storing fecal matter, garbage and water without seeding, in the same proportions as given above, since October 23, 1934, or a period of 93 days.

The characteristics of this material are given in Table I.

TABLE I.—*General Characteristics of Garbage, Human Fecal Matter, and Seeded Sludge Used*

Materials	Moisture, %	Ash, %	Volatile Solids, %	Ether Soluble Matter, %	Total Nitrogen, %	pH
Garbage	85.4	0.1	14.5	0.15	0.27	
		(0.4)	(99.6)	(1.1)	(1.9)	
Excreta and Urine (Sample "A")	96.5	0.6	2.9	0.15	0.6	8.0
		(16.5)	(83.5)	(4.4)	(17.3)	
Do. (Sample "B")	95.7	0.9	3.4	0.32	—	8.0
		(21.0)	(79.0)	(7.3)		
Do. (Sample "C")	96.2	0.7	3.1	0.18	0.73	8.8
		(18.6)	(81.4)	(4.6)	(19.2)	
Ripe Sludge	96.7	(34.8)	(65.2)	(2.5)	(11.9)	7.5

* Figures in ( ) denote percentage on dry solids basis.
Sample "A" represents the material aged for 3 days.
Sample "B" represents the material aged for 10 days.
Sample "C" represents fully decomposed material aged more than 10 days.
Average age of garbage is 2 days.

At every dosing time the fecal matter, garbage and water were mixed with 0.5 liter of the ripe sludge withdrawn from the digester. The time of mixing was varied from one to five minutes, according to the character of the material to be added and the pH value of the digester. Air was introduced into the digester by this procedure.

Continuous daily dosing began January 19, 1935, and surplus sludge and liquor were not withdrawn until January 28th. Daily addition and withdrawal continued to the end of this experiment on March 3, 1935, keeping the tank contents always near 26 liters.

Throughout this experiment, the garbage used was of almost uniform character, while the human fecal matter was of various kinds. The general characteristics of the materials are indicated in Table I.

Gas Yield and pH Value.—Gas production and the variations of pH values are shown in Fig. 2. The average gas production was 8.07 liters

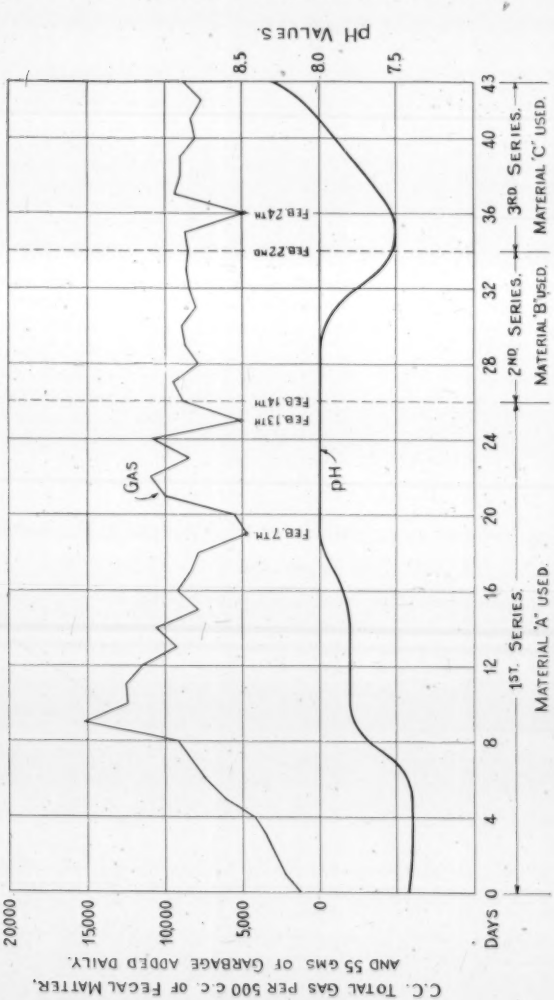

FIG. 2.—Daily gas production from the digestion of human fecal matter and garbage seeded with ripe sludge. Fresh material was not added on Feb. 24th, but addition was doubled on the next day.

per day, equal to 16.14 liters per capita per day, based on an average daily per capita production of 1.0 liter of feces and urine and 110 grams of garbage.

The composition and heat values of the gas are shown in Table II.

TABLE II.—*Chemical Analyses and Heat Values of Gas from the Digestion of Human Fecal Matter and Garbage*

Date	Fecal Matter Used	pH	CH_4, %	CO_2, %	H_2, %	O_2, %	N_2, %	Total Heat Value, B.t.u. per Cub. Ft.
Feb. 2....	Sample "A"	7.8	58.7	18.1	1.9	1.7	19.6	632
Feb. 15....	Sample "A"	8.0	55.4	24.0	2.5	1.3	16.8	607
Feb. 23....	Sample "B"	7.5	51.0	29.8	1.4	1.0	16.8	556
Mar. 2....	Sample "C"	8.3	41.0	20.9	1.4	0.0	36.7	447

The total heat values, shown in the last column, indicate that the lowest gas yield was obtained when using fully decomposed fecal matter. From these analytical results, the optimum pH value for digestion of human fecal matter and garbage might be assumed to be 7.8 or below, perhaps a little higher than the settling tank sludge, owing to the higher initial pH value of the fecal matter.

The End Products.—The chemical analyses of the digested materials are indicated in Table III.

TABLE III.—*Analyses of Digested Sludge from the Digestion of Human Fecal Matter and Garbage*

Date	Moisture, %	Ash, %	Volatile Solids, %	Ether Soluble Matter, %	Total Nitrogen, %	pH
Jan. 29....	96.6	43.0	57.0	(10.5)	(1.61)	7.8
Feb. 19....	93.7	38.2	61.8	(5.5)	(1.15)	7.9
Mar. 11....	94.7	38.5	61.5	(8.2)	(1.11)	8.3

* Figures in ( ) denote percentage on dry solids basis.

Comparing the results in Table III with the analyses of the raw materials, it appears that the percentage reduction of volatile matter was nearly 16 per cent on a dry solids basis. This reduction is considerably less than is usually obtained in the digestion of sewage sludge. Nevertheless, observation indicated that there was comparatively satisfactory progress of digestion. The author believes that the reduction of volatile matter would have been greater if it had been possible to open in full the

2-inch valve, with which the outlet of the experimental digester was equipped, so that flooding could have been avoided. With this imperfect apparatus, portions of partially digested sludge were discharged. The end products had a faint fecal odor, but were free from pathogenic bacteria and parasitic eggs, when tested on several occasions.

The ash content of the end product was less than the digested sewage sludge used for seeding. In the case of digestion of fecal matter the ash content is not a determining factor of the progress or of the completion of digestion, as the materials themselves contain only a small amount of ash.

Supernatant Liquor.—The supernatant liquor was more concentrated than that obtained from sewage sludge digesters, but it can be handled by sand filtration, as shown in Table IV.

TABLE IV.—*Chemical Analyses of Supernatant Liquor*

	Raw		Filtrate	
	%	p.p.m.	%	p.p.m.
Moisture	98.2		99.9	
Total Solids	1.8	18,110	0.1	730
Suspended Solids	0.56	5,660	0.02	110
	(31.2)		(15.1)	
Dissolved Solids	1.24	12,450	0.08	620
	(68.8)		(84.9)	
B. O. D.		890		190
Total Nitrogen	(33.7)	6,100	(11.6)	100
Ammonia Nitrogen		4,640		54
Albuminoid Ammonia Nitrogen		260		8
Lipids	(19.9)	1,790	(9.0)	145
Bacteria, 1000/c.c.	4,890		4,740	
B. Coli	(Could not be distinguished)		(Could not be distinguished)	
pH	8.3		8.3	

* Figures in ( ) denote percentage on dry solids basis.

Very rapid filtration was obtained by pouring 500 cc. of the raw liquor over a sand bed 12 cm. square by 15 cm. deep.

Discussion.—Experiment I may be divided into three series. In the first series, using fresh fecal matter "A" with garbage, air was introduced into the mixtures every day by stirring for about four or five minutes. The pH value increased from 7.4 to 8.0 at the end of this series as shown in Fig. 2, but lag of gas production occurred twice, on

Feb. 7th and 13th. These lags might have been due to rising pH values, or to the character of the garbage, composed mostly of "TOFU" (very watery pudding-like Japanese food made of the soya-bean), used on these two days. The fecal matter "B," aged for 10 days with ordinary garbage, was used at the commencement of Series II, and no aeration of the mixtures was practiced. It was found that the pH value had decreased from 8.0 to 7.5 at the end of the experiment.

Series III was run mainly to test the relationship of the character of the materials used and the gas yield, and also to determine the effect of aeration on the fully decomposed fecal matter. During this period, fully decomposed or half-septicized fecal matter was mixed with garbage and very little air was supplied to the mixtures by stirring for a short period, say for about one minute. The quality of the gas produced during this period was quite inferior, and the pH value again increased from 7.5 to 8.3.

It seemed to the author that aeration had less effect upon the decomposed fecal matter, the nitrogen of which had mostly changed to ammonia salts, than upon the fresh material, since the change of pH value was slow compared with the result in the first series and in spite of using the fecal matter of such a high initial pH value as 8.8.

II. Digestion of Human Fecal Matter Alone

The purposes of this experiment were (1) to ascertain the character and quantity of the gas yield by such materials as human feces and urine, which had been digested alone, and the optimum pH for digestion; (2) to check the results obtained in the previous experiment, especially regarding the effect of aeration on the pH value of the digesting sludge. It was thought that a test with single materials would show its relationship more distinctly.

The experiment was run from March 23 to May 10, 1935, using the experimental installation as previously described. Continuous dosing was adopted, with a daily dosage of 500 cc. of human fecal matter mixed with 400 cc. of ripe sludge, withdrawing sludge from the digester daily, and keeping the tank temperature at about 32° C.

The character of the materials and ripe sludge used was similar to the analyses given in Table I. At the start, there were 5.0 liters of ripe sludge and 19 liters of supernatant liquor, remaining from Expt. I; the normal contents of the digester were kept at about 24.0 to 25.0 liters throughout the experiment. The experiment might be divided into two sections: the first to observe the effect of the age of the materials on the variation of the pH value during digestion; the relationship between the age of the materials and the character of the gas produced; the sec-

ond to check the variation of the pH values corresponding to the aeration applied to the mixtures. These sections might be again subdivided into six series for the convenience of explanation.

The "B" class of material (see Table I) was used in the 1st series, then "C" for the 2nd series, again "B" for the 3rd series; and "A" material for the 4th series. Throughout this experiment aeration of the mixtures was entirely avoided, because the main purpose was to investigate the characteristics of the gas produced, as correlated with the age or the character of the materials used, and at the same time to record the variation of the pH values. It was thought possible that the aeration might influence the pH value to some extent in the digestor.

In the 5th and 6th series, the materials used were fresher than "A," being aged on the average for one day and a half. The proeedure in the second was employed mainly to determine whether the air applied internally would affect the pH value in the course of digestion. The reason for using less aged material was that human fecal matter decomposes very rapidly. This is illustrated in Fig. 3, where it is shown that the initial pH value of 6.1 increased to 7.9 after the lapse of one day. The use of "fresher" material might be even more decisive.

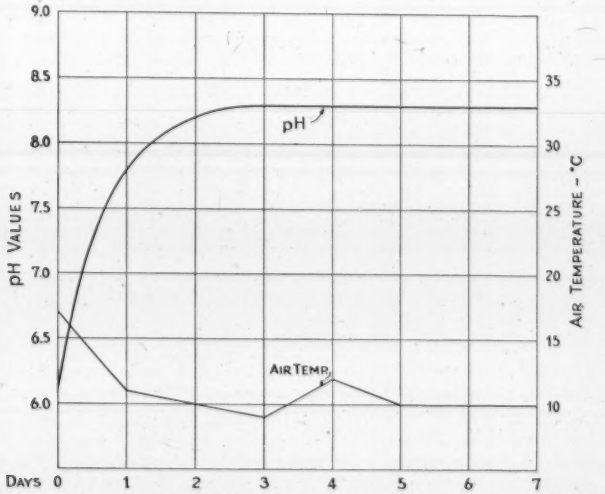

FIG. 3.—Variation of pH values of human excreta and urine when exposed to the air.

Character and Quantity of the Gas Produced.—The character of the gas produced is indicated by the analyses reported in Table V. An aver-

TABLE V.—*Chemical Analyses and Heat Values of Gas Produced from the Digestion of Human Fecal Matter Alone*

Date	Fecal Matter used	pH	CH_4, %	CO_2, %	H_2, %	O_2, %	N_2, %	Total Heat Value, B.t.u. per Cub. Ft.
Apr. 1.....	Sample "B"	8.2	55.9	16.7	0.0	0.0	27.4	593
Apr. 10.....	Sample "C"	8.2	47.0	21.5	1.5	0.6	29.4	509
Apr. 23.....	Sample "A"	8.0	56.7	18.5	2.1	0.6	22.1	615

* For the characteristics of the samples refer to Table I.

age daily production of 4.47 liters (Fig. 4), with daily additions of 500 cc. of the human excreta and urine in normal ratio, is indicated. The highest heat value of the gas was obtained at a pH value 8.0, that is to say, by the use of the freshest raw material, and gas with lowest heat value was obtained from old and half septicized material.

Although the optimum pH value was not ascertained in this experiment, it is conceivable that a better gas could have been produced if even fresher fecal matter had been used, provided the optimum stage would be below 8.0.

The data from Tables I, VI, and and VII, indicate a total gas production of 219.2 liters during 49 days' test, corresponds to 540 cc. of gas per gram of volatile matter, reduced to a dry solids basis.

If these figures can be taken as illustrative, the human fecal matter would yield a greater quantity of gas than is generally appreciated.

The pH Value as Affected by Introducing Air Into the Mixtures.—In the preceding paragraph, it has been stated that the age and character of the added materials affect the pH value during digestion, when not accompanied by aeration of the mixtures.

In the second section, 5th and 6th series, it was attempted again to show how the pH values would vary with and without an air supply to the mixtures. Enough air was supplied to the 1½ day old fecal matter to keep it fresh by aerating about five minutes at every dosing time.

The results obtained during the last stage (Fig. 4) illustrate the increase of the pH value from 8.0 at the beginning of the 5th series to 8.7 at the end of the period. By stopping aeration of material of the same character in the 6th series, there was again a decrease to 8.2. The same pH value was maintained after discontinuing addition of fresh material.

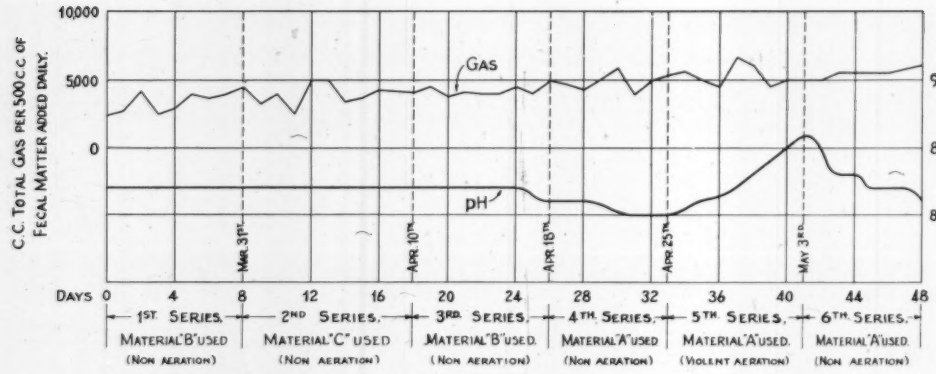
10,000
5000
0
C.C. TOTAL GAS PER 500 C.C. OF FECAL MATTER ADDED DAILY.
GAS
pH
9.0
8.5
8.0
pH VALUES
MAR. 31ST.
APR. 10TH.
APR. 18TH.
APR. 25TH.
MAY 3RD.
DAYS 0 4 8 12 16 20 24 28 32 36 40 44 48
1ST. SERIES. MATERIAL "B" USED (NON AERATION)
2ND SERIES. MATERIAL "C" USED (NON AERATION)
3RD. SERIES. MATERIAL "B" USED. (NON AERATION)
4TH. SERIES. MATERIAL "A" USED (NON AERATION)
5TH SERIES. MATERIAL "A" USED. (VIOLENT AERATION)
6TH. SERIES. MATERIAL "A" USED. (NON AERATION)

FIG. 4.—Daily gas production from the digestion of human fecal matter, and relation of pH values to the age of the materials, and to the intensity of aeration.

Digested Material and Supernatant Liquor.—The characteristics of the end product and supernatant liquor are given in Tables VI and VII. The rate of volatile matter reduction was again low in comparison with sewage sludge digestion.

TABLE VI.—*Analyses of Digested Sludge from the Digestion of Human Fecal Matter Alone*

Date	Moisture, %	Ash, %	Volatile Solids, %	Ether Soluble Matter, %	Total Nitrogen, %	pH
Mar. 30.....	95.9	31.0	69.0	(17.0)	(1.60)	8.2
Apr. 17.....	96.1	33.8	66.2	(9.8)	(1.62)	8.2

* Figures in ( ) denote percentage on dry basis

TABLE VII.—*Chemical Analyses of Supernatant Liquor*

Moisture, %	Total Solids, %	Ash, %	Volatile Solids, %	Suspended Solids, p.p.m.	Dissolved Solids, p.p.m.	B.O.D. p.p.m.	Total Nitrogen, p.p.m.	Lipids, p.p.m.	pH
98.0	2.0	27.9	72.1	4,010	16,040	853	5,900	1,080	8.1

No trace of pathogenic bacteria and parasitic eggs was found in the digested product or the liquor.

SUMMARY AND CONCLUSIONS

From the studies of pH adjustment by air control during the digestion of human fecal matter, the following conclusions might be drawn:

1. When air is applied internally to the added material, and the added fresh solids are properly seeded with ripe sludge, the pH value is affected during digestion.

2. The pH adjustment by air control is most effective when fresh material is used.

3. Human excreta and urine of normal composition yield gas of fairly good character and quantity at the optimum stage of pH value, similar to that obtained with sewage sludge digestion.

4. The end product produced under these conditions does not contain pathogenic organisms or parasitic eggs.

To confirm items (1) and (2) the author wishes to call attention to the tendency toward high pH values in the digestion of activated sludge. The high pH values might be due to an excess of air in the sludge. The fact that the digestion of settling tank sludge, when mixed with activated

sludge in proper percentages, is accelerated might be attributed to the effect of the excess air in the activated sludge adjusting the pH value of the whole mixture.

No attempt has been made to discuss how the aeration of the mixture of the added material and ripe sludge could affect the chemical, biological or bio-chemical processes during digestion, or the effect caused by the removal, during mixing, of the gases present in the ripe sludge used as seeding material, as these questions are entirely beyond the scope of the author's studies.

The author expresses his appreciation for the help of Mr. S. Shibata, Chief Chemist, Tokio Sewage Dept. in the laboratory work during these experiments, and thanks are due Dr. Willem Rudolfs, Chief, Department of Sewage Research, N. J. Agricultural Experiment Station, who has kindly guided him since 1927 in the study of this problem.

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OXYGEN UTILIZATION BY ACTIVATED SLUDGE

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Control of operation of activated sludge plants is based on the visual appearance of the sludge, and on analytical results obtained on the influent, mixed liquor and effluent. Only occasionally in the literature do oxygen studies appear, aside from the customary five-day rate for the B.O.D., on the influent and effluent.

A review of the theory of activated sludge action by Edwards [1] gave nine references to work done on the oxygen requirements of the process, only three of which directly related to the amount of oxygen actually used in the biochemical oxidation process. In 1926 Harris, Cockburn and Anderson,[2] by reaerating 5 per cent activated sludge repeatedly with aerated water, and determining the amount of dissolved oxygen remaining in the supernatant, found that after practical equilibrium was established the sludge used 105 mg. of oxygen per hour per liter of sludge. These authors did not state the amount of suspended solids in the sludge used. Theriault and McNamee [3] working with "channel sludges" of 10,000 p.p.m. suspended solids found that oxygen was utilized at the rate of 89 p.p.m. per hour. The quality of the sludge which these workers used probably was quite different from that found under normal operating conditions of an activated sludge plant. Grant, Hurwitz and Mohlman,[4] in one of a series of experiments in which activated sludge was furnished pure oxygen dissolved in dilution water in a special apparatus, found that oxygen was used at the average rate of 150 p.p.m. per hour during the first hour.

One of the major items of cost of the activated sludge process is that of power required for aeration. Many varieties and designs of aeration equipment, both of the diffused air and mechanical types, have been developed in an attempt to provide aeration at a lower cost, but little special study has been devoted to the problem of requirement or utilization of oxygen.

During a series of experiments designed to test the efficiency of one of these aerators with respect to pounds of oxygen furnished per unit power cost, difficulty was encountered in ascertaining the rate of oxygen utilization.

Mr. Carl H. Nordell became interested in the test and when confronted with our problem he showed us some results which were included

in a report [5] which he made when he was Engineer of Design for the Milwaukee Sewerage Commission. Mr. Henry Heisig, now Chief Chemist of Milwaukee Sewerage Commission was associated with Mr. Nordell at that time in the design experiments.[5] Because of the priority of this unpublished work and its bearing on our problem we include a summary below.

Nordell's Design Experiments, Milwaukee, Wisconsin, 1917

The results were obtained from experimental apparatus consisting of two spiral-flow aeration tanks, each of 40 gallons capacity, fitted with air-flow manometers and operated on a fill-and-draw basis. The rate of oxygen utilization of activated sludge was obtained as follows: Sewage and sludge mixture was aerated over a long period to establish a base rate and to furnish an oxygen concentration high enough for the experiments. Five one-half gallon bottles were then simultaneously filled

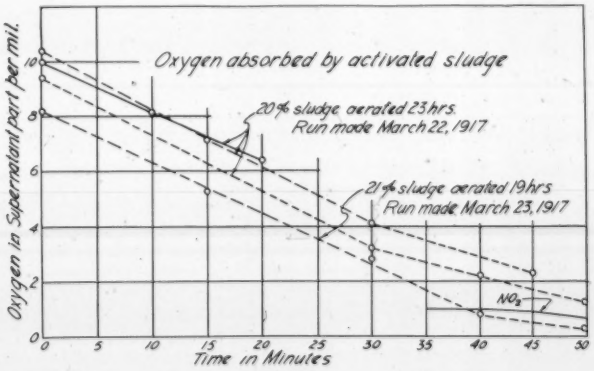

Fig. 1.

with the aerated mixture. Number 1 was allowed to settle immediately, number 2 was agitated to keep the sludge mixed with the liquid for fifteen minutes before it was allowed to settle, number 3 for thirty minutes, number 4 for forty minutes and number 5 for fifty minutes. After allowing each bottle the same period of time for settling, the dissolved oxygen was determined on each supernatant, respectively. The results on what Mr. Nordell called at that time "oxygen absorbed" are given in Figure 1.

It will be noted that the rate of utilization of oxygen by fully oxidized activated sludge was found to be independent of the quantity of dissolved oxygen present in the supernatant liquor. That is shown definitely in the run made March 23, at which time all five points were obtained. The slight break in the curve at thirty and forty minutes was attributed by Nordell to the presence of nitrites. Nordell interpreted these results in his report as follows: "This points unmistakably to the fact that the sludge absorbs oxygen from the water just as rapidly when there are only a few parts per million in solution as it does when the water is almost saturated. . . . If the sludge gets as much oxygen out of the liquor at a low degree of saturation, it would seem that the present practice of maintaining a comparatively high oxygen content in the aerating tanks is wasteful, for only a small proportion of the oxygen in the air can then be dissolved out of it." Nordell reported some very interesting data on the oxygen requirements of sludge when freshly dosed with sewage. The method of ascertaining this rate of utilization of oxygen was essentially the same as he used for the base rate on activated sludge alone. The results of one of Nordell's typical runs is shown in Figure 2. His comment on this curve was "It will be noticed

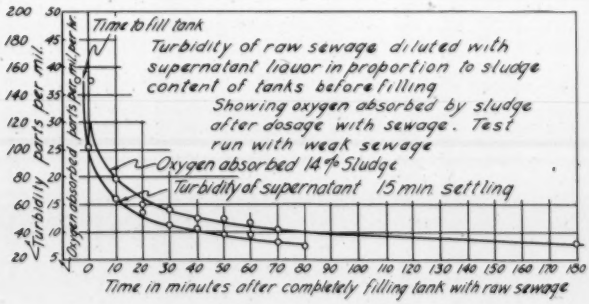
Time to fill tank
Turbidity of raw sewage diluted with supernatant liquor in proportion to sludge content of tanks before filling
Showing oxygen absorbed by sludge after dosage with sewage. Test run with weak sewage
Oxygen absorbed 14% Sludge
Turbidity of supernatant 15 min. settling
Turbidity parts per mil.
Oxygen absorbed parts per mil. per hr.
Time in minutes after completely filling tank with raw sewage

FIG. 2.

that the oxygen is absorbed three times as rapidly when the tank is first filled as it does ninety minutes later and four times as fast as it does three hours later. This would make it appear that the first tanks in a continuous flow series might well receive a greater proportion of air." He also stated " that an exact test for sludge well activated may be devised." He also gives data in a curve (his number VIII)[5] not shown here that the rate of oxygen utilization by a sludge is almost in direct proportion

to its percentage in the aerating mixture. In a sludge 28 per cent by volume after thirty minutes settlement, the rate of utilization was four times that of sludge containing 5 per cent by volume. He also noted the now well recognized fact that the rapidity of purification appears to be in direct proportion to the percentage of sludge present in the aerating mixture.

These findings of Nordell have been applied and extended under his direction to the efficiency study of the aerator which was under investigation. With certain modifications made necessary by the nature of our sludge, we used his original methods of obtaining the rate of oxygen utilization by sludge and sewage-sludge mixtures. This rate in all cases has been computed to an hourly basis, because of the rapidity of oxygen utilization, and expressed in parts of oxygen utilized per million parts of sludge or sewage-sludge mixture. This "rate," because of his early work and its present applications to activated sludge evaluations both as to its activity and condition, we choose to call the "Nordell Number."

The modifications used consisted principally in using a coagulant to facilitate sludge settlement. Copper sulphate, suggested by John R. Palmer and A. J. Beck of the Chicago Sanitary District, was found not only to cause rapid sludge settlement but to stop oxygen utilization immediately upon its addition to a sludge or sewage-sludge mixture. It was found to have one disadvantage in that the cupric ion liberated an equivalent of iodine in any subsequent dissolved oxygen determination so that a correction is necessary unless simply differences are all that are required as is the case in finding a Nordell Number.

It is well known that oxidation takes place in the presence of living matter under two very different conditions. Aerobic oxidation is that type which occurs in the presence of atmospheric oxygen and anaerobic oxidation that type which is manifest without the presence of atmospheric oxygen. In either case the action proceeds by virtue of catalysts. In the former case aerobic oxidation is exemplified by the action of activated sludge while an example of the latter, anaerobic oxidation, is given by sludge digestion tanks. There is evidence that the line of demarcation between these two types of oxidation is decidedly obscure and that all gradations of oxidation occur if conditions become favorable. Such a set of conditions probably obtains at times in the activated sludge process. It is rather a common experience with activated sludge to find no dissolved oxygen, or at least the lowest dissolved oxygen in the tanks receiving the incoming sewage, yet satisfactory action takes place. In order to determine the rate of oxidation under all these conditions of dissolved oxygen it was found necessary to modify the procedure so that the four following methods were found necessary:

Methods for the Determination of the Rate of Oxygen Utilization by Activated Sludge or Sewage-Sludge Mixtures

(Nordell Number)

The Nordell Number is the rate of oxygen utilization in parts by weight of oxygen per million parts of liquid sludge, or liquid sewage-sludge, per hour. It is calculated from data showing the rate of disappearance of dissolved oxygen over short periods of time usually from three to ten minutes and then calculated to an hourly basis for the interval observed.

1. *Direct Method.*—This method was used when the sludge or sewage-sludge mixture contained sufficient dissolved oxygen so that a residual quantity above 1.5 p.p.m. was still present at the end of the incubation time, three to ten minutes. Two half-gallon large-mouthed bottles were completely filled simultaneously with the aerated sludge or sewage-sludge mixture. Turbulence in filling the bottles was kept the same and at a minimum during the filling of both bottles. To one, bottle *A*, was added 10 ml. of a ten per cent solution of $CuSO_4.5H_2O$ below the surface and then both bottles were stoppered without the entrainment of air bubbles. Bottle *A* was inverted a few times to mix the copper sulphate, after which the floc that formed immediately was allowed to settle. The second bottle *B* was shaken or agitated for a period of time sufficient to cause a depletion of about 2.0 p.p.m. of dissolved oxygen, determined by trial. In no case was the dissolved oxygen (D.O.) content used if found to be below 1.5 p.p.m. which meant that the initial D.O. was above 3.5 p.p.m. if this direct method was applied.

After the agitation period of bottle *B*, 10 ml. of ten per cent copper sulphate solution was added; the contents mixed well and permitted to settle. Finally, after the floc in both bottles had settled for about ten minutes, the supernatant from each was siphoned off into 250 ml. bottles (completely flushing all bottles) and the D.O. determination made by the Winkler method, provided nitrites and ferric iron were absent. Two ml. each of the $MnSO_4$, alkaline KI, and H_2SO_4 were used as suggested by Theriault [6] to increase the rate of oxygen absorption. The time of shaking before acidification was twenty seconds. The difference between the D.O. content of the two supernatants was the reduction in parts per million for the period of shaking of bottle *B*. This reduction was converted to a Nordell Number by computation to p.p.m. per hour. Because of the large amount of clear supernatant present in the half-gallon bottles it was always possible to set up two and usually three 250 ml. bottles, so a check run was possible in making the D.O. determination.

2. *Aeration Method.*—If the mixed liquor of sludge or sewage-sludge mixture had a low D.O. content it was increased by agitation with air. Two one-gallon bottles were filled about three-fourths full with the mixed

liquor of low D.O. content and then violently shaken or aerated for about three minutes until the mixed liquors contained a high D.O. content. The contents of each gallon bottle were poured simultaneously into two half-gallon bottles until each was about half filled, then the bottles were alternated and the pouring continued until the two half-gallon bottles were filled. Thereafter the procedure was the same as given under "Direct Method 1."

3. *Dilution Method.*—This method was used when the D.O. of the tank mix was low but greater than zero. A half-gallon bottle *A* was calibrated by marking the elevations of liquid surface at $\frac{1}{2}$, $\frac{2}{3}$, $\frac{4}{5}$, $\frac{9}{10}$ full with strips of paraffined adhesive tape on the outer periphery of the bottle and this "dilution" bottle was almost filled with aerated tap water (non-chlorinated). A siphon was inserted and a 250 ml. bottle was filled for a D.O. test on this dilution water. The siphon was allowed to waste until the water level reached the mark of the required dilution. To a second empty half-gallon bottle *B* was added 10 ml. of copper sulphate solution. Then both bottles were partially immersed simultaneously with the large-mouthed openings facing each other in the tank mix. Time was taken when the tank mix had half-filled the space above the dilution water of bottle *A*. After both bottles were completely filled and stoppered, bottle *B* was inverted to mix well and the contents allowed to settle. The dilution mix, bottle *A*, was shaken for the time period, after which further oxidation was inhibited and coagulation facilitated by the addition of 10 ml. of copper sulphate solution, with subsequent mixing before settling.

The supernatants from bottles *A* and *B* were siphoned off for D.O. determinations. By knowing the D.O. on the original tank mix, bottle *B*, the dilution mix, bottle *A* and the dilution water used, we were able to compute the Nordell Number. Methods 2 and 3 were found to give comparable results. In Table I is a sample computation of the dilution method (3):

TABLE I

Item	Description	Result
1	Dilution (1/2 aerated water + 1/2 tank mix)	
2	Time dilution mixture was shaken	6 min.
3	D.O. found in tank mix bottle *B*	4.4 p.p.m.
4	D.O. found in dilution water	8.9 p.p.m.
5	D.O. found at end of time period bottle *A*	4.8 p.p.m.
6	Computed D.O. bottle *A* initially $\frac{4.4 + 8.9}{2}$	6.65 p.p.m.
7	D.O. depletion in dilution mix bottle *A*, 6.65 − 4.8	1.85 p.p.m.
8	Computed depletion tank mix for time period was 2 × 1.85 (since dilution mixture was only half tank mix)	3.7 p.p.m.
9	Nordell Number = 60/6 × 3.7	37.0 p.p.m. (1 hr.)

4. *Double Dilution Method.*—This method was used when the D.O. of the tank mix was very low, zero or less than zero. It is a modification of the dilution method (3) in that the tank mix bottle *B* was also calibrated and partially filled with dilution water of a known D.O. content. Thus both bottles containing dilution water were partially immersed at the same time in the tank mix and the technique was similar to that outlined under method (3) except that the copper sulphate solution was added after the tank mix bottle *B* was filled, and time reckoned from that operation. The calculation of the rate of oxygen usage was similar to that shown in Table I except cognizance must be taken of the dilution in bottle *B*.

The Immediate Oxygen Demand or Minus Oxygen Level

When the dilution method of running a Nordell Number was applied to our particular sewage-sludge mixtures of zero D.O., different results for different periods of shaking were obtained. For example, if the period of shaking of the dilution mix was five minutes, we obtained a higher Nordell Number than when the period was ten minutes. Because of this finding we tried running a Nordell Number with about three seconds period of shaking and the number was tremendously high, which did not appear reasonable. This would indicate that the Nordell Number might vary if the period of shaking varied. To study this point, we decided to develop a curve by tests that would indicate the amount of oxygen depleted over various periods of time of shaking.

Using the mixed liquor from a properly conditioned sludge, taken from the large mechanical aeration tank under experimental investigation, the procedure of obtaining the Nordell Number by the dilution method (3) was followed for periods of shaking varying from one-half to six minutes.

The results shown in Table II and Figure 3 were obtained from a study of the immediate effect of incoming raw sewage on the aeration sludge mixture. The depletion of oxygen by the sludge in the dilution water bottle, shown during the first one-half minute and one-minute periods were inordinately high. Thereafter, the rate of usage of oxygen while varying slightly from minute to minute is quite uniform and the experimental points permit a straight line to be drawn, the slope of which shows the average rate of usage or Nordell Number for this particular sewage-sludge mixture. The initial high rate or immediate oxygen demand of the raw sewage itself for the first minute in this raw sewage activated sludge mixture can be evaluated by finding the point of interception on the *y*-axis, if the curves are extended in a straight line to the point of zero time. Because of this immediate oxygen demand the Nor-

TABLE II.—*Reduction of Dissolved Oxygen in Tank Mix per Time Period*

Time Samples were Taken from Aerator A.M.	Period Sludge was Mixed Without Atmospheric Contact Min.	Dilution Portion of Bottle Filled with Sewage	D.O. of Dilution Water P.P.M.	Computed D.O. of Diluted Mix P.P.M.	Actual D.O. of Diluted Mix P.P.M.	Reduction of D.O. in Dilution Mix Per Period P.P.M.	D.O. Used by Mixed Liquor Per Time Interval P.P.M.
August 21, 1934							
10:00	1	1/3	8.3	5.5	4.4	1.1	3.3
10:05	3	1/3	8.0	5.3	4.0	1.3	3.9
10:45	1/2	1/3	8.5	6.7	4.9	0.8	2.4
10:50	2	1/3	8.4	6.6	4.7	0.9	2.7
11:10	3	1/3	8.6	5.7	4.1	1.6	4.8
11:15	4	1/3	8.7	5.8	3.9	1.9	5.7
August 22, 1934							
10:50	1/2	1/3	8.7	5.8	4.9	0.9	2.7
10:55	1	1/3	8.9	5.93	4.5	1.43	4.3
11:00	2	1/3	8.8	5.9	4.3	1.6	4.8
11:05	3	1/3	8.7	5.8	4.0	1.8	5.4
11:07	4	1/3	8.6	5.7	3.4	2.3	6.9
11:17	6	1/3	8.4	5.6	2.9	2.7	8.1
11:27	1	1/3	8.7	5.8	4.3	1.5	4.5

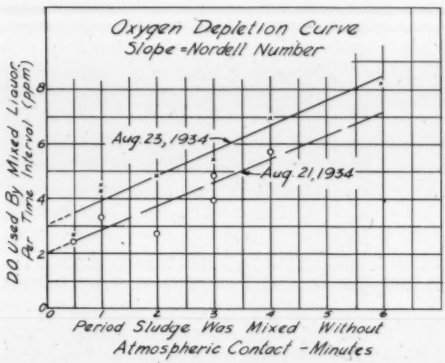

FIG. 3.

dell Number (or rate of oxygen utilization) was found by determining not the initial depletion with respect to time but the depletion in the three- to ten-minute interval after the immediate demand was satisfied. The immediate oxygen demand in this case can be considered as a minus oxygen level or that amount of oxygen necessary to bring the dissolved oxygen of the sewage, sludge, or sewage-sludge mixture up to zero oxygen and satisfy the immediate chemical demand. Thereafter the metabolism of the sewage, sludge or sewage-sludge mixture uses oxygen at a fairly uniform rate for short periods of time.

Condition of an Activated Sludge Which Shows No Dissolved Oxygen by the Winkler Test

During the study of this minus oxygen level we became interested in developing a laboratory technique to investigate more fully the utilization of oxygen by the sludge after the free oxygen in the liquid was exhausted.

It will be obvious that if a sludge contains no D.O. and the biological action is still active, oxidation and reduction are still taking place. We know that if the mixed liquor in an activated sludge tank is set aside in a tightly stoppered bottle, the D.O. of the mixture will drop to zero. If this sludge remains for a longer period in the bottle and then is aerated for a very short period, twenty to thirty seconds, the Winkler test still indicates no dissolved oxygen. Therefore, the oxygen supplied during the short aeration period may have been utilized by the sludge because of the immediate or practically instantaneous demand. Nordell [7] offers an explanation of this phenomena as follows: "Activated sludge has the property of adsorbing a considerable amount of oxygen upon its surfaces and the velocity of adsorption is very great indeed. This adsorbed film of oxygen, oxidizes the organic material at a definite rate" (Nordell Number) "which is much slower in comparison, and as fast as the adsorbed film is used it is replaced by adsorption of more free oxygen from the surrounding liquid. If the supply of oxygen in the surrounding liquid is exhausted, the oxidation of the organic material proceeds and the rate" (Nordell Number) "does not change until the film is considerably reduced." Perhaps the sludge deoxidizes some of the organic material to such a state that it can instantaneously use dissolved oxygen. The following experiments were made to study the conditions obtaining when dissolved oxygen was absent from the sewage-sludge mixture.

Well conditioned sludge was dosed into raw sewage and aerated in a small twenty-five gallon spiral-flow aeration tank until the D.O. content became quite high. Using three operators, five large-mouthed half-

gallon bottles *A*, *B*, *C*, *D* and *E* were filled simultaneously with the tank mix and tightly stoppered; initial time being taken when the bottles were half filled. Bottle *A* initially contained 10 ml. of ten per cent copper sulphate solution and the D. O. test was run immediately on the supernatant of this bottle, as described elsewhere. Throughout the remainder of the test, all bottles were shaken by hand or machine. At the end of five minutes, bottle *B* was dosed with copper sulphate solution and the D.O. test run on the supernatant. The low D.O. result of bottle *B*, Table III indicated that further tests would have to be run by the dilu-

TABLE III.—*Oxygen Level of Sludges after Various Periods of Time Without Additional Contact With Free Oxygen*

Interval Period Sludge was Mixed Without Atmospheric Contact Mins.	Dilution Portion of Bottle Filled with Sewage	D.O. of Dilution Water P.P.M.	Computed D.O. of Diluted Mix P.P.M.	Actual D.O. of Diluted Mix P.P.M.	Oxygen Level of Sludge at End of Interval P.P.M.
August 22, 1934					
0	1				4.6
5	1				0.6
10	1/2	8.0	4.0	2.8	−2.4
20	1/3	8.3	5.5	4.3	−3.6
60	1/10	7.9	7.1	6.5	−6.0
August 23, 1934					
0	1				7.1
10	1				5.1
40	1/2	8.6	4.3	4.1	−0.4
60	1/3	8.6	5.7	5.5	−0.6
60	1/3	8.1	5.4	5.2	−0.6
140	1/3	7.9	5.3	4.7	−1.8

tion method. At the end of ten minutes, the stopper of bottle *C* was removed. Immediately it was replaced by a two-hole stopper equipped with glass and rubber tubing so that the contents of the bottle when inverted could be transferred to another bottle C_1 of equal volume that had been half-filled with tap water of a known D.O. content. As soon as bottle C_1 was filled, it was stoppered and inverted two or three times to mix the sludge with the dilution water, then copper sulphate was added and the D.O. test conducted. A similar procedure was followed on bottles *D* and *E* at the end of twenty and sixty minutes, respectively. Table III indicates the results obtained and is the supporting data for

Figure 4. It will be observed from Table III that on August 23, two tests were conducted at the sixty-minute interval. One bottle had been shaken continuously and the other was shaken about once every five minutes. Apparently the continuity of mixing did not have any effect on the oxygenation of the sludge.

Figure 4 shows that for some period of time, the oxygen level or dissolved oxygen concentration continues to decrease at a constant rate to

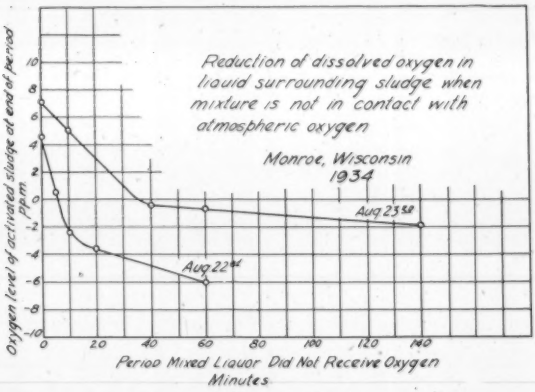

FIG. 4.

and through zero to a point below zero which we believe depends upon the condition of the sludge. For the uniform slope portion of the curve, the Nordell Number is constant. The latter portion of the curve representing the oxygen level is nearly horizontal and therefore the Nordell Number (rate of usage of oxygen) is at that level practically zero. This horizontal portion of the curve probably represents a period of transition between aerobic and anaerobic oxidation. An example of this anaerobic oxidation is encountered in batch digestion of Imhoff sludge wherein the production of CO_2, as shown by the gasification curve, becomes a measure of the rate of anaerobic oxidation.

COPPER SULPHATE SOLUTION—ITS PLACE IN THE DETERMINATION OF D.O. OF MIXED LIQUORS

Because of the action of copper sulphate on biologic life, the use of oxygen is immediately stopped and coagulation, flocculation and settling is accelerated leaving a clear supernatant for the D.O. test. Early in

the work it was found desirable to conduct D.O. determinations on several supernatant liquids at the same time. Since some of these supernatants had been standing for ten minutes and others for thirty minutes or more, it was necessary to know whether or not the D.O. had changed on standing after the copper sulphate was added. A series of supernatants from similar sewage-sludge mixtures were prepared accordingly and D.O. determined after varying periods of time. The results are shown in Table IV.

TABLE IV

Material in Half-Gallon Bottle	Dissolved Oxygen by Winkler Test After Dosage with Copper Sulphate Solution for Various Time of Contact with Sludges	
	10 Min.	60 Min.
Plant Effluent	9.15	9.0
Plant Effluent	6.58	6.65
1/10 Sludge + 9/10 Tap Water	9.65	9.55
1/10 Sludge + 9/10 Tap Water	9.60	9.55
1/5 Sludge + 4/5 Tap Water	9.30	9.30
1/5 Sludge + 4/5 Tap Water	9.5	9.45
1/2 Sludge + 1/2 Tap Water	7.75	7.90
1/2 Sludge + 1/2 Tap Water	7.6	7.55
All Activated Sludge	6.1	6.0
All Activated Sludge	6.0	6.05

These results show that for at least a period of one hour there was no appreciable change in the D.O. concentration of the supernatant liquid. All oxidation seems to have been inhibited.

APPLICATION OF FOREGOING TECHNIQUE TO THE DEVELOPMENT OF A NEW THEORY ON THE OXYGENATION OF SEWAGE BY THE ACTIVATED SLUDGE PROCESS

The effect of sewage strength upon the rate of usage of oxygen (Nordell Number) is a question that was not touched upon in the early Milwaukee experiments and as far as we know it has not been investigated closely by any former experimenters. Furthermore the B.O.D. test at that time was not in general use and turbidity was the useful parameter. The copper sulphate technique which cleared away many technical difficulties now permits us to examine the Nordell Number curve of Figure 2 in detail in the early moments of treatment after inoculation of sewage with sludge.

A mechanical aerator[8] was used to provide sludge that had been through cycles of uniform aeration periods. It was operated under a constant sewage volume load which gave the mixed liquor constant aeration and settling periods. When a Nordell Number curve was to be

determined, mixed liquor from the large aerator was placed in the small twenty-five gallon spiral diffused air aeration tanks at the laboratory and allowed to settle. The supernatant was then drawn off and replaced with a volume of raw sewage. This raw sewage was the same as that which the sludge would have received had it been left in the large mechanical aeration unit. Immediately after the addition of the raw sewage to the small tanks, aeration was started. This was taken as the zero time of the curve. The total elapsed time from the instant the mixed liquor was taken from the mechanical aerator until zero time on the curve was never more than seventy minutes. The small tanks, then were going through the same process which takes place in an actual activated sludge plant, namely, concentration of sludge, addition of sludge to raw sewage, and aeration of mixed sludge and raw sewage.

For the test of August 24, small tanks number 1 and 2 were operated in parallel after mixing the concentrated activated sludge contents of both tanks and pouring 7.8 gallons into each tank. Tank number 1 was filled with 13.4 gallons of raw sewage later found to have a B.O.D. of 1100 p.p.m. Tank number 2 was filled with five gallons of water with a B.O.D. of 10 p.p.m. and 8.4 gallons of raw sewage with a B.O.D. of 1100 p.p.m. Thus both tanks contained 21.2 gallons of mixed liquor (sludge freshly dosed with raw sewage) with number 1 having the greatest strength. The sludge occupied about 37 per cent of the volume of both tanks. Table V indicates the results of these tests. It will be observed that after a ninety minute time interval (dosing of the sludge with raw sewage) the dissolved oxygen of the mixed liquor in the tanks was high enough so as to permit the use of the direct method (1) in place of the dilution method (3). Figure 5 shows the plotting of these data. From the amount of water and sewage added to tank number 2, it will be observed that the resultant mixture was approximately 63 per cent as strong as the sewage alone. The result of the test shows that when weak sewage was treated it took only 63 per cent as long for the Nordell Number to reach a given value as it did when the stronger sewage was treated. Note that the Nordell Number was *not* 63 per cent of that of the stronger sewage, but that the time required to reach the same Nordell Number was 63 per cent as long. The indication is that when sewages of the same relative composition but of different strengths are aerated with identical quality and quantity of sludges, the time required for the Nordell Number to fall to a given level is directly proportional to the strength of the sewage. For example on Figure 5 the tank mix in tank number 1 reached a Nordell Number of 15.0 in nine hours, while the same number was reached by the tank mix of tank number 2 in 5.75 hours or only 63 per cent as long as that required by the stronger sewage.

TABLE V.—*Rate of Utilization of Oxygen by Activated Sludge-Sewage Mixtures*

Time Elapsed After Start of Aeration	Period of Shaking the Dilution Mix	Dilution Portion of Bottle Filled with Sewage	D.O. in Aeration Tank (Tank Mix)	D.O. of Dilution Water	D.O. of Dilution Mix at End of Period	Computed Initial D.O. of Dilution Mix	Reduction of D.O. in Dilution Mix per Period	Reduction of D.O. in Tank Mix per Period	Nordell Number
Hr. Min.	Min.		p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m./hr.
Tank No. 1									
0–5	5	1/3	−1.0	8.1	3.5	5.07	1.59	4.7	56.5
			.3?	8.0	3.5	5.4	1.9	5.7	68.4
0–25	6	1/3	0.4	8.0	3.5	5.3	1.8	5.4	54
1–00	6	1/2	2.5	8.1?	2.9	5.3	2.4	4.8	48
			2.5	8.7	2.9	5.3	2.7	5.4	54
1–30	6	1/2	4.4	8.9	4.8	6.65	1.85	3.7	37
2–00	6	1	5.8	—	2.8	—	—	3.0	30
2–30	6	1	6.1	—	3.4	—	—	2.7	27
4–38	6	1	6.3	—	4.1	—	—	2.2	22
7–30	11	1	6.7	—	3.6	—	—	3.1	17
24–00	10	1	8.3	—	6.6	—	—	1.7	10
48–00	10	1	9.6	—	8.8	—	—	0.8	5
72–30	10	1	7.9	—	6.9	—	—	1.0	6
Tank No. 2									
0–5	6	1/3	0.5	8.1	3.6	5.4	1.8	5.4	54
0–25	6	1/3	2.5	8.1	4.5	6.2	1.7	5.1	51
1–00	6	1/2	4.5	8.1	4.5	6.3	1.8	3.6	36
			4.5	8.7?	4.5	6.6	2.1	4.2	42
1–30	6	1	6.0	—	3.4	—	—	2.6	26
2–00	6	1	6.3	—	4.0	—	—	2.3	23
2–30	6	1	6.4	—	4.2	—	—	2.2	22
4–38	6	1	6.7	—	4.8	—	—	1.9	19
7–30	11	1	7.1	—	4.4	—	—	2.7	14.7
24–00	10	1	8.2	—	6.8	—	—	1.4	8.4
48–00	10	1	10.0	—	9.0	—	—	0.95	5.7
72–30	10	1	7.9	—	7.1	—	—	0.80	4.8

Furthermore it should be observed from Figure 5 that the maximum Nordell Number of identical sludges dosed with strong sewage is the same as the maximum number arrived at when the sludge is dosed with a weaker sewage. Evidently a sludge of given condition or activity has a maximum rate of oxidation which is reached in a short period of time when freshly dosed with sewage regardless of the strength of the sewage.

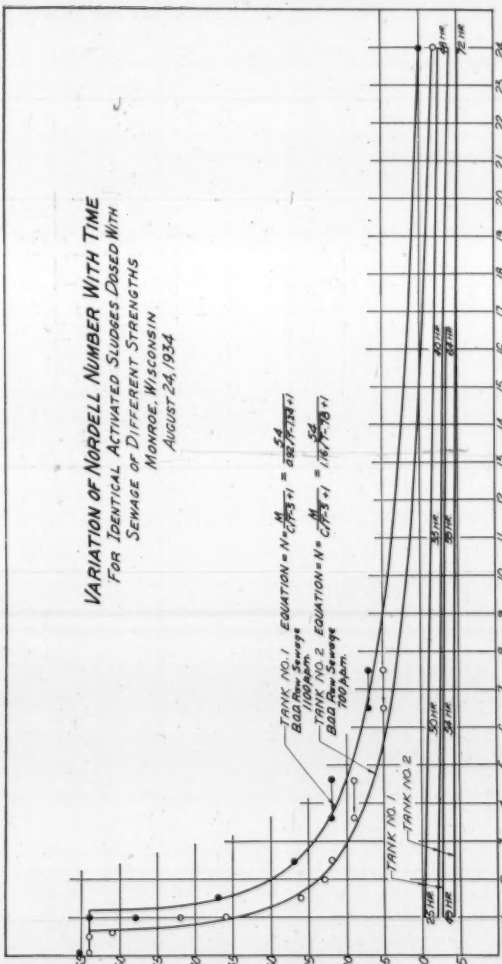
VARIATION OF NORDELL NUMBER WITH TIME
FOR IDENTICAL ACTIVATED SLUDGES DOSED WITH
SEWAGE OF DIFFERENT STRENGTHS
MONROE, WISCONSIN
AUGUST 24, 1934
TANK NO. 1 EQUATION = N = M/(C(T-3)+1) = 54/(0.92(T-1.24)+1)
B.O.D. Raw Sewage 1100 p.p.m.
TANK NO. 2 EQUATION = N = M/(C(T-3)+1) = 54/(1.16(T-.78)+1)
B.O.D. Raw Sewage 700 p.p.m.
TANK NO. 1
TANK NO. 2
25 HR.
42 HR.
30 HR.
34 HR.
35 HR.
38 HR.
40 HR.
64 HR.
48 HR.
72 HR.
TIME IN HOURS.
NORDELL NUMBER-PPM. OXYGEN PER HOUR

FIG. 5.

This rate usually persists for a measurable length of time and then decreases; at first very rapidly and then more slowly, as seen from Figure 5. The length of time during which the maximum rate of oxidation persists was shown by this experiment to be in proportion to the strength of the sewage.

Development of a Mathematical Expression for Rate of Utilization of Oxygen by Activated Sludges

Nordell devoted much study to these data and curves and arrived at an empirical equation that can be used to determine the strength of the sewage undergoing treatment by the activated sludge process, the condition of the activated sludge and the progress of the treatment process. This equation is based on rates of oxidation in parts per million per hour (Nordell Number) and is believed to be of sufficient importance that it is reported here in detail.

The curves through the points of Figure 5 were first "smoothed up" and the results appeared to be quite precise, especially for the readings of "N" on number 1 tank, where "N" is a variable indicating the Nordell Number at the time "T." "T" is the time in hours reckoned from the instant sludge is first dosed with sewage and the aeration process started. "M" is the maximum Nordell Number possible for a given sludge. "S" is the period of time in hours during which "M" persists; (it is apparently directly proportional to the sewage strength, B.O.D.). Nordell then expressed the value of "N" at any time "T" after the duration of the maximum rate of oxygen usage "M" for the time "S" as follows:

$$N = \frac{M}{C\sqrt{T - S} + 1} \qquad \text{Equation (1)}$$

where "C" is a constant the square of which (C^2) apparently is inversely proportional to sewage strength, "S" in time units.

Subsequent determinations with the assistance of Mr. P. F. Morgan, research assistant, indicate that "M" is approximately directly proportional to the weight of the volatile portion of the suspended solids or sludge carried in the tank mix. This observation is in general agreement with the finding of Grant, Hurwitz and Mohlman.[4] It appears to be a quantity or measure indicative of quality or condition of sludge or "sludge activity."

For the results on tank number 1, the best values of "C" and "S" to fit the experimental points were 0.92 and 1.24 respectively. The expression then becomes:

$$N = \frac{54}{0.92\sqrt{T - 1.24} + 1} \qquad \text{Equation (2)}$$

The computed and observed values of "N" from Fig. 5 are given in Table VI below:

TABLE VI

"T" in Hours	"N" Computed	"N" Observed from Tank 1, Fig. 5	Variation of Computed Nordell Numbers from Observed Values
0.08	54.	54.	0.0
0.50	54.	54.	0.0
1.0	54.	54.	0.0
1.5	36.7	37.	−0.3
2.0	29.9	30.	−0.1
2.5	26.5	27.	−0.5
4.63	20.0	22.	−2.0
7.5	16.3	17.	−0.7
24.0	10.0	10.	0.0
48.0	7.4	5. (NO_2)?	+2.4
72.0	6.2	6.	+0.2

Considering the curve obtained on tank number 2, Figure 5, it became evident that "S" was 63 per cent of the 1.24 value from curve of tank number 1, or 0.78. Solving equation (1) for "C" by using the observed values of the Nordell Number on tank number 2 of Table V at the respective time periods, "C" will be found to vary from 1.02 to 1.27 and to have an average value of about 1.16. Therefore, substituting the value 0.78 for "S" and 1.16 for "C" in equation (1), the equation for the curve of tank number 2 Figure 5 becomes:

$$N = \frac{54}{1.16\sqrt{T - 0.78} + 1} \qquad \text{Equation (3)}$$

In Table VII is shown the agreement between the computed values of "N" using equation (3) and the values obtained by experiment.

Equation (1) can be rewritten and "C" placed under the radical in the expression $C\sqrt{T - S}$ which becomes $\sqrt{C^2T - C^2S}$ and then equation (1) becomes:

$$N = \frac{M}{\sqrt{C^2T - C^2S} + 1} \qquad \text{Equation (4)}$$

substituting the respective values "C" = 0.92 and "C" = 1.16 for curves obtained on tanks 1 and 2, the numerical value of the quantity under the radical is $\sqrt{0.846T - 1.05}$ for tank 1 and $\sqrt{1.346T - 1.05}$ for tank 2. It will be seen that the C^2T values for unit time are to each other, respectively, as 0.63 is to 1.0. Furthermore the value of C^2S for the curves of both tanks became a constant value of 1.05 and we believe for practical purposes C^2S can be taken as unity. Therefore from the

TABLE VII

"T" in Hours	"N" Computed	"N" Observed from Tank 2, Fig. 5	Variation of Computed Nordell Numbers from Observed Values
0.08	54.	54.	0.0
0.50	54.	51.	+3.0
1.0	35.	36.	−1.0
1.5	27.2	26.	+1.2
2.0	23.5	23.	+0.5
2.5	21.4	22.	−0.6
4.63	16.5	19.	−2.5
7.5	13.6	15.	−1.4
24.0	8.2	8.	+0.2
48.0	6.0	5.4	+0.6
72.0	4.95	4.8	+0.15

above consideration (C^2) is inversely proportional to the strength of the sewage "S" expressed in time units as determined on the Nordell Number curves of Figure 5 ($C^2 = 1/S$).

Thus it has been found that for identical activated sludges treating similar sewages but of varying strength "S," the maximum rate of usage of oxygen "M" for that sludge multiplied by the sewage strength "S" in time units is a constant varying directly with the sewage strength "S." This value we designate as "K" because it takes into account the maximum rate of usage of oxygen possible "M" with any given sludge which "S" fails to do, then $MS = K$. From above $S = 1/C^2$ and $S = K/M$ therefore $C^2 = M/K$. Since C^2 by experimental investigation has been found to vary directly with "M," the maximum Nordell Number for a sludge of definite "activity" and "C^2" varies inversely with the strength of the sewage, then by substituting for C^2 its equal M/K equation (4) can be rewritten as follows:

$$N = \frac{M}{\sqrt{(MT/K) - 1} + 1} \qquad \text{Equation (5)}$$

This equation indicates that "K" is a dimensional quantity in parts per million of oxygen. Therefore at any given activated sludge plant if the B.O.D. of the raw sewage activated sludge mixture that is being treated is determined in the usual way, and as the B.O.D. bottles are set up, the Nordell Number curve is determined, we find that the B.O.D. divided by the value "K" will give a factor "F," or "K" multiplied by "F" will give an equivalent B.O.D. This relationship points a way to a B.O.D. determination on the incoming sewage in an hour's time or less after "F" has been established.

Nordell Number curves have been obtained at several activated sludge plants during the past year. It has been found that the factor "F"

mentioned above varies from one plant to another. At Monroe, Wisconsin "*F*" is about 10.0, while at Williams Bay, Wisconsin, Milwaukee, Wisconsin and Newark, New York, it has varied between 6.0 and 13.0.

Solving equation (5) for "*K*" we get

$$K = \frac{MT}{(M - N/N)^2 + 1} \qquad \text{Equation (6)}$$

"*K*" = parts per million of oxygen per some unit of time depending on the value of "*F*." It is directly a measure of the sewage load on a plant and is of such a nature that it can be established by the operator in one hour.

Application of Nordell Number Curves to a Study of Activated Sludge Plant Operation

Characteristic oxygenation curves are shown in Figure VI representing conditions found at a given plant. The maximum Nordell Number "*M*" has a definite relationship with the Nordell Number "*N*" found at time "*T*" when oxidation in the treatment process has progressed to completion, that is, a high B.O.D. reduction has taken place and the sludge has been conditioned for further use. This ratio of "*M*" to "final *N*" varies among the plants tested between the ratio of 3 : 1 to 6 : 1. The ratio of $M : N$ of 4 : 1 is a fair or average conclusion as far as experiments of this research project have progressed.

Therefore the three curves of Figure 6 should be considered as representing rates of oxygenation at a given locality where sludges are being built up by treatment of a particular composition of sewage and that experimental work has shown that curve number 2, Figure 6 with a "*K*" of 50 and an "*M*" of 50 approximates the normal oxygenation rate of the respective sewage and sewage sludge. Furthermore that B.O.D. tests on the plant effluent have indicated a high reduction in B.O.D. at the end of a 10.0 hour period of aeration at which time the Nordell Number "*N*" has a value of 12.5 p.p.m. per hour. Then in this case the ratio of the maximum Nordell Number "*M*" to the Nordell Number "*N*" when the effluent of the mixed liquor after settling will be ready to be disposed of by directing it into the outfall of the plant, is 50/12.5 or 4 : 1 as has been explained above.

Under another condition assume that the plant operator returns more sludge to the raw sewage or increases the quantity of volatile suspended solids so that the "activity" of the sludge is doubled, then curve number 1 will result with an "*M*" of 100 and the same sewage strength represented by a "*K*" of 50. Now with the exception of the required rate of oxygenation at the one-hour aeration period Figure 6, the rate of usage of oxygen is materially increased throughout the treatment process. Knowing that the 4 : 1 ratio between the new "*M*" of 100 and the final

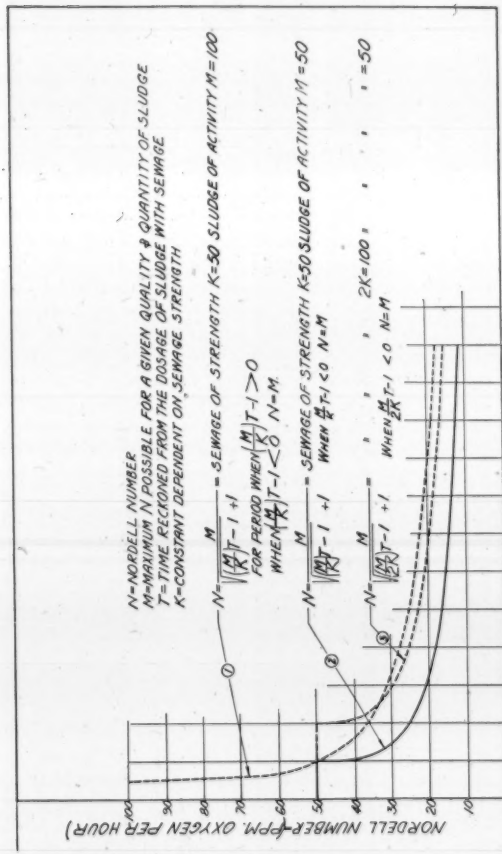
N=NORDELL NUMBER
M=MAXIMUM N POSSIBLE FOR A GIVEN QUALITY & QUANTITY OF SLUDGE
T=TIME RECKONED FROM THE DOSAGE OF SLUDGE WITH SEWAGE
K=CONSTANT DEPENDENT ON SEWAGE STRENGTH
N = M / (K/M T - 1 + 1) = SEWAGE OF STRENGTH K=50 SLUDGE OF ACTIVITY M=100
FOR PERIOD WHEN (K/M) T - 1 > 0
WHEN (K/M) T - 1 < 0 N = M
N = M / (K/M T - 1 + 1) = SEWAGE OF STRENGTH K=50 SLUDGE OF ACTIVITY M=50
WHEN K/M T - 1 < 0 N = M
N = M / (K/M T - 1 + 1) = " " " 2K=100 " " " =50
WHEN K/2M T - 1 < 0 N = M
NORDELL NUMBER (PPM. OXYGEN PER HOUR)
TIME IN HOURS

Fig. 6

Nordell Number "*N*" when the oxidation in the treatment process is finished, we find this final Nordell Number to be 25.0 p.p.m. per hour. This Nordell Number will occur at the 5.0 hour period of aeration and the oxidation process will have produced a complete treatment of the sewage and conditioned the sludge so that a high reduction in B.O.D. would be shown by the plant effluent. The difference between the two final values of "*N*" of 25.0 and 12.5 respectively, is due obviously to the usage of oxygen by the increased amount of sludge and not to a component of partially treated sewage. This is shown by the fact that the B.O.D. of the final effluent in each case is approximately the same. Therefore it can be concluded that, provided the existing plant has sufficient aeration capacity so as to produce the required amount of oxygenation per hour and has the final settling capacity to clarify the higher percentage of activated sludge floc, curve number 1, Figure 6 shows that the same sewage being treated by sludge of *twice* the activity will produce effective treatment of the sewage in *one-half* the time. It follows that the capacity of the plant for treatment would be doubled provided hydraulic design and hydraulic and mechanical difficulties in settling the floc can be overcome.

Under still another condition, curve number 3, Figure 6, indicates the change in the rate of oxygenation when the plant has been operating as in curve number 2 but is suddenly asked to treat a sewage of twice the strength or $2K = 100$. The rate of oxygenation need not be increased, but it will require a given rate of oxygenation over an aeration period *twice* as long. In curve number 2 we find the ratio of "*M*" to final "*N*" of 4:1 or the final "*N*" is 12.5 p.p.m. per hour occuring at the end of the 10.0 hour period for a satisfactory B.O.D. reduction and sludge conditioning. The time for the 4:1 ratio of "*M*" to "*N*" to occur on curve number 3 will be, by computation, 20.0 hours. It is quite likely that the average activated sludge plant would not have this additional period of aeration.

Application of Theory and Technique to Studies Made at Several Activated Sludge Sewage Plants

In addition to the extended studies made at Monroe, Wisconsin, it was considered advisable to make practical application of the procedures to sludges of several other plants to see what correspondence could be obtained between observed and calculated data. Among those plants visited were Williams Bay, Wisconsin, Milwaukee, Wisconsin, Newark, N. Y., Morristown, Madison-Chatham and Bernardsville, N. J., Flora, Illinois, and the experimental mechanical aerator which was being operated full scale at the Madison, Wisconsin, Burke Sewage Works.

The following tables indicate a summary of a few of the experimental observations on the rate of oxygen utilization by activated sludges and

TABLE VIII.—*Milwaukee, Nov. 8, 1934*

Time Elapsed After Start of Aeration Hours	Period of Shaking the Dilution Mix Minutes	Reduction of D.O. in Tank Mix per Period	Observed Nordell Number p.p.m. per hour	Computed Nordell Number $N = \frac{M}{\sqrt{\frac{MT}{K} - 1} + 1}$
.217	7	9.40	80.5	80.0
.516	7–3	5.75	49.0	49.6
.767	6	3.60	36.0	39.6
1.400	10	5.00	30.0	30.1
2.200	10	4.35	26.6	24.9
2.870	10	4.50	27.0	22.3
4.130	10	3.70	22.2	19.2

Laboratory Tank No. 1: Filled with 22.8 gallons sewage-sludge mixture from inoculation channel of Milwaukee Plant with a B.O.D. of tank mixture of 280, suspended solids about 3,000 p.p.m., with 22.3 per cent ash or 2,340 p.p.m. volatile solids. Settling curve = 18 per cent in 30 minutes.

M = 80.0; and K = 30.0 used in equation for computed Nordell Numbers shown in last column.

Then B.O.D./K = F = 280/30 = 9.3.

TABLE IX.—*Milwaukee, Nov. 18, 1934*

Time Elapsed After Start of Aeration Hours	Period of Shaking the Dilution Mix Minutes	Reduction of D.O. in Tank Mix per Period	Observed Nordell Number p.p.m. per hour	Computed Nordell Number $N = \frac{M}{\sqrt{\frac{MT}{K} - 1} + 1}$
.05	4	1.80	27.0	24.0
.10	4	1.50	22.5	24.0
.15	5	2.00	24.0	24.0
.20	5	1.70	20.4	24.0
.30	6	2.30	23.0	24.0
.50	6	2.10	21.0	16.6
.51	4	1.28	19.4	16.4
.75	4–2	0.90 *	13.5	12.7
1.00	5	0.90	10.8	11.0
1.63	10	1.65	9.9	8.9
5.10	15	1.95	7.8	5.5

* Rideal-Stewart modification used with Winkler test.

Laboratory Tank No. 2 contained 2.4 gallons of well conditioned sludge from experiments of previous day, having B.O.D. of effluent of 9.5. Then 15.8 gallons of sewage was added (120 B.O.D.) making a total tank mixture of 18.2 gallons with a B.O.D. of 106. Suspended solids = 900 p.p.m., with 22.2 per cent ash, or 701 p.p.m. volatile solids. Settling curve = 7 per cent in 30 minutes.

M = 24.0; and K = 10.0 used in equation for computed Nordell Numbers shown in last column.

Then B.O.D./K = F = 106/10 = 10.6.

TABLE X.—*Milwaukee, Dec. 1, 1934*

Time Elapsed After Start of Aeration Hours	Period of Shaking the Dilution Mix Minutes	Dilution-Portion of Bottle Filled with Sludge	Reduction of D.O. in Tank Mix per Period	Observed Nordell Number p.p.m. per hour	Computed Nordell Number $N = \frac{M}{\sqrt{\frac{MT}{K} - 1} + 1}$
.050	4	1/2	9.14	137.0	137.0
.100	4	1/2	6.70	101.0	137.0
.150	5	1/2	10.50	126.0	118.5
.200	5	1/2	7.44	89.3	85.3
.300	6	1/2	7.84	78.4	67.6
.500	6	1/2	7.14	71.4	53.5
.567	4	—	2.85	42.7	50.8
1.000	10	—	5.45	32.7	40.1
2.500	10	—	4.60	27.6	27.4

Laboratory Tank No. 2 was filled with 4.0 gallons of well conditioned sludge (B.O.D. = 10) from Run No. 1 of the same day. Then 7.7 gallons of sewage of 300 B.O.D. was added, making a total tank mix of 11.7 gallons with a B.O.D. of 201, suspended solids = 5,650 p.p.m., with 30.6 per cent ash, or 3920 p.p.m. of volatile solids. Settling curve = 32 per cent in 30 minutes.

$M = 137$; and $K = 20.0$ used in equation for computed Nordell Numbers shown in last column.

Then B.O.D./$K = F = 201/20 = 10$.

B.O.D. at 46 minutes = 20.0 and after 82 minutes aeration = 9.0.

TABLE XI.—*Newark, N. Y., Dec. 30, 1934*

Time Elapsed After Start of Aeration Hours	Period of Shaking the Dilution Mix Minutes	Reduction of D.O. in Tank Mix per Period	Observed Nordell Number p.p.m. per hour	Computed Nordell Number $N = \frac{M}{\sqrt{\frac{MT}{K} - 1} + 1}$
.05	4	1.10	16.50	19.00
.10	4	1.30	19.50	19.00
.15	5	1.64	19.70	19.00
.20	5	1.54	18.50	19.00
.30	6′–5″	1.86	18.35	19.00
.50	4	1.36	20.40	19.00
.75	4′–3″	1.20	17.80	19.00
2.00	10	1.90	11.40	11.30
3.70	14	2.50	10.70	8.24
17.40	10	.88	4.88	4.32

4.0 gallons of sludge from Division Box at Newark Plant of B.O.D. of 35.0 was placed in Laboratory Tank No. 1. Then 18 gallons of settled sewage from clarifier of 404 B.O.D. was added, making B.O.D. of sewage-sludge mixture = 337.0 by computation.

Suspended solids at end of 1 hour = 950 p.p.m. Settling curve = 18 per cent sludge in 30 minutes.

$M = 19$; $K = 26$. 337 B.O.D./26 = B.O.D./$K = F = 12.95$.

TABLE XII.—*Newark, N. Y., Dec. 31, 1934*

Time Elapsed After Start of Aeration Hours	Period of Shaking the Dilution Mix Minutes	Reduction of D.O. in Tank Mix per Period	Observed Nordell Number p.p.m. per hour	Computed Nordell Number $N = \frac{M}{\sqrt{\frac{MT}{K} - 1 + 1}}$
.05	4	1.90	28.50	48.0
.10	4	1.54	23.10	48.0
.15	5	1.64	19.70	48.0
.20	5	1.90	22.80	48.0
.30	6	1.90	19.00	48.0
.50	4′–2″	3.35	49.80	48.0
.75	6	3.55	35.50	27.4
1.00	10	4.55	27.30	23.4
2.00	10	2.75	16.50	17.3
18.71	11	1.60	8.72	6.7

4.3 gallons of sludge (poor condition) B.O.D. estimated at 35.0 was placed in Laboratory Tank No. 1. To this was added 19.0 gallons of raw sewage later determined to have a B.O.D. of 360. Therefore sewage sludge mixture had a B.O.D. of 300 by computation.

Suspended solids at 2 hours = 2,288 p.p.m. Settling curve = 64 per cent sludge in 30 minutes. $M = 48$; $K = 24$. 300 B.O.D./$K = F = 300/23 = 13.1$.

After 18 hours 48 minutes aeration was stopped with 11.3 gallons of mixed liquor remaining. Settling curve = 50 per cent in 30 minutes (note improvement in settling).

(See January 1, 1935.)

TABLE XIII.—*Newark, N. Y., Jan. 1, 1935*

Time Elapsed After Start of Aeration Hours	Period of Shaking the Dilution Mix Minutes	Reduction of D.O. in Tank Mix per Period	Observed Nordell Number p.p.m. per hour	Computed Nordell Number $N = \frac{M}{\sqrt{\frac{MT}{K} - 1 + 1}}$
.083	4	3.20	48.00	48.0
.20	5	4.24	51.00	48.0
.30	6	3.80	38.00	36.0
.50	4	1.65	24.80	25.1
.75	6	2.10	21.00	20.6
1.00	10	2.95	17.70	18.2
3.31	10	3.60	21.60	11.1

After 11.3 gallons of mixed liquor of run of December 31st had settled for 2 hours (B.O.D. effluent 12.0); then 7 gallons of supernatant was decanted by siphoning, leaving 4.3 gallons of well conditioned sludge. Then 7.0 gallons of raw sewage, B.O.D. of 260, was added and Nordell Number curve conducted as above. Computed B.O.D. of sewage-sludge mixture = 166.

Suspended solids present after 2 hours = 2,457 p.p.m. Settling curve = 52 per cent in 30 minutes. $M = 48$; $K = 13.0$. 166 B.O.D./$K = F = 166/13 = 12.75$.

TABLE XIV.—*Newark, N. Y., Nordell Number Survey on Large Plant Aerator, Jan. 4, 1935*

From Beginning of Aeration (Feet)	Time Elapsed After Start of Aeration of Mixed Liquor (Hours, Minutes)	Period of Shaking the Dilution Mix	Dilution-Portion of Bottle Filled with Sewage	D.O. in Aeration Tank (Tank Mix)	D.O. of Dilution Water	D.O. of Dilution Mix at End of Period	Computed Initial D.O. of Dilution Mix	Reduction of D.O. in Dilution Mix per Period	Reduction of D.O. in Tank Mix per Period	Observed Nordell Number
1.0′	0–6	6	1/2	1.00	9.84	3.0	5.42	2.42	4.84	48.4
74.0′	7–28	6	1/2	.95	9.40	4.7	5.17	0.47	0.94	9.4

Raw sewage flow was by Venturi flume at a rate of 1,050,000 gallons per day + 195,000 gallons/day of return sludge or a discharge of 1.925 c.f.s. of mixed liquor into aerators of which there are two in number. For the South aerator under investigation, the rate of flow divided by the cross-sectional area of the tank gave a mean forward velocity from beginning of aerator to end of aerator of 0.165 feet per minute. Therefore the raw sewage-sludge mixture should have arrived at end of spiral flow, diffused air-paddle wheel aerator 74 feet in length, at the end of 7 hours and2 8 minutes.

Suspended solids test indicated 1,900 p.p.m. with settling rate of 58 per cent in 30 minutes. $M = 48.0$ and $T = 7.47$ hours. Then

$$K = \frac{MT}{\left(\frac{M-N}{N}\right)^2 + 1} = \frac{48 \times 7.47}{\left(\frac{48-9.4}{9.4}\right)^2 + 1} = 20.0.$$

Since F = B.O.D./K = about 13.0 from other tests at Newark, then B.O.D. of settled sewage from preliminary clarifier should have been $K \times F = 13.0 \times 20.0 = 260.0$. B.O.D. bottles set up January 4th, 1935, and incubated at 20 deg. C. until January 9, 1935, gave B.O.D.'s as follows: 255, 235, 330, 230. Final effluent B.O.D.'s ran 32, 34, 39.

TABLE XV.—*Morristown, N. J., Jan. 9, 1935*

Distance from Point of Entry of Raw Sewage in Feet	Time Elapsed After Start of Aeration in Hours	Period of Shaking the Dilution Mix in Minutes	Reduction of D.O. in Tank Mix per Period	Observed Nordell Number	Computed Nordell Number
(Tank No. 1)					
0	0.017	5	2.8	33.6	34.0
23	0.330	6	2.0	20.0	34.0
62	0.890	8	3.2	24.0	23.3
138	2.000	10	2.5	15.0	14.7
276	4.000	10	1.8	10.8	10.9

Suspended solids = 1,620 p.p.m. Settling curve = 86 per cent in 30 minutes. $M = 34$; $K = 25$.

TABLE XVI.—*Bernardsville, N. J., Jan. 10, 1935*

Place Sewage Mix Sample Taken	Time Elapsed After Start of Aeration in Hours	Period of Shaking the Tank Mix in Minutes	D.O. in Aeration Tank (Tank Mix) at Beginning of Time Period	D.O. of Tank Mix at End of Time Period	Reduction of D.O. in Tank Mix per Period	Observed Nordell Number	Computed Nordell Number
Mixing channel at entry to aerators	0.00	6	2.50	1.30	1.20	12.0	12.00
Beginning spiral aerator	0.05	3	2.15	1.55	0.60	12.0	12.00
End of Tank No. 1 41.5 ft. out	3.00	10	4.15	2.95	1.20	7.2	7.34
Middle of second aerator 62.5 ft. out	4.50	10	5.65	4.65	1.00	6.0	5.78
End of last aerator 82 ft. out	6.00	10	6.80	5.95	0.85	5.1	5.07
In effluent channel enroute to final clarifier	6.05	10	6.95	6.15	0.80	4.8	5.07

Suspended solids = 700 to 800 p.p.m. Settling curve = 15 per cent in 30 minutes $M = 12$; $K = 25$.

TABLE XVII.—*Madison-Chatham, N. J., Jan. 11, 1935*

Place Sewage Mix Sample Taken	Time Elapsed After Start of Aeration in Hours	Period of Shaking the Tank Mix in Minutes	D.O. in Aeration Tank (Tank Mix) at Beginning of Time Period	D.O. of Tank Mix at End of Time Period	Reduction of D.O. in Tank Mix per Period	Observed Nordell Number	Computed Nordell Number
Mixing channel	Approx. 0.050	4	5.62	3.50	2.12	31.80	—
Mixing channel	Approx. 0.050	4	4.45	3.50	0.95	14.20	14.00
Beginning, Aerator No. 1	0.05 to 0.170	7	4.40	3.00	1.40	12.00	14.00
37 ft. out, Aerator No. 1	0.292	8	2.85	1.35	1.50	11.25	14.00
74 ft. out, Aerator No. 1	0.526	6	2.95	2.05	0.90	9.00	14.00
110 ft. out, end of Aerator No. 1	0.873	7	4.05	2.95	1.10	9.43	14.00
220 ft. out, end Aerator No. 2	1.790	10	6.05	4.78	1.28	7.68	7.80
330 ft. out, end Aerator No. 3	2.620	10	6.65	5.65	1.00	6.00	6.36
440 ft. out, end Aerator No. 4	3.490	10	7.30	6.35	0.95	5.70	5.60
550 ft. out, end of Aerator No. 5	4.360	10	6.90	6.05	0.85	5.10	5.10
660 ft. out, end Aerator No. 6	5.230	10	6.15	5.35	0.80	4.80	4.71

Suspended solids = 1,040 p.p.m. Settling curve by Mr. Paul Molitor, Sr. = 12 per cent in 30 minutes. $M = 14$; $K = 15$.

TABLE XVIII.—*Experimental Mechanical Aerator, Madison, Wisconsin, Mar. 9, 1935*

Time Elapsed After Start of Aeration (Hours)	Period of Shaking the Dilution Mix in Minutes	Reduction of D.O. in Tank Mix per Time Period	Observed Nordell Number	Computed Nordell Number
0.05	4	3.50	52.5	52.0
0.17	5	4.28	51.3	52.0
0.30	6	4.20	42.0	52.0
0.42	6	4.04	40.4	40.5
0.50	6	3.48	34.8	33.5
0.59	6	3.00	30.0	30.2
1.00	6	2.60	26.0	23.0
2.00	8	2.62	19.7	17.0
3.00	10	2.10	12.6	14.4
4.00	10	2.40	14.4	12.9
5.00	10	1.55	9.3	11.6
24.00	10	1.10	6.6	6.3

$M = 52$; $K = 20$.

the respective agreement with calculated values. It will be noted that the tables include a considerable range in strength of sewages tested and various concentrations of suspended solids in the sewage-sludge mixtures.

SUMMARY

A method or technique has been developed for the determination of the rate of utilization of oxygen by raw sewage-activated sludge mixtures at any period of time during the treatment process and based on some original observations by Carl H. Nordell. The rate of utilization of oxygen found by experiment is given in parts per million per hour and is termed the Nordell Number to distinguish it from the usual biochemical oxygen demand. The method used consists essentially of noting oxygen depletions in sewage-sludge mixtures over short periods of time. This was made possible by a simplified technique involving the use of copper sulphate solution as a coagulation and flocculation agent and as an arrester of biologic oxidation.

The rate of oxygen utilization can be used to ascertain the progress of oxidation of the sewage as it passes through the activated sludge treatment process. Furthermore, by adapting the method used and the use of dilution water of known dissolved oxygen content, the working condition of any activated sludge-sewage mixture can be found even though no dissolved oxygen is present, as frequently happens in some plants.

From the data obtained on the rate of usage of oxygen, curves were plotted from which an equation was developed. This equation provides

a means for finding the time necessary for completion of the treatment process. The equation when written in another form permits the determination of sewage strength comparable with B.O.D. within a period of one hour.

Conclusions

1. We believe the theory and experimental investigation as outlined in this paper will point a way whereby many activated sludge plants can be operated more successfully and economically.

2. Activated sludges must be given the required amount of free oxygen and as the treatment process progresses, this quantity can be decreased in accordance with the Nordell Number obtained.

3. The Nordell Number, rate of utilization of oxygen in parts per million per hour, of sewage and sewage-sludge mixtures and the equations presented, provide the plant operator with a simple means of determining sewage strength, the stage of oxidation, and the condition of "activity" of sludge within a short period of time usually less than one hour.

Studies are under way which take into account the rate of oxygen utilization of sewage-sludge mixtures with respect to the volume of sludge present. At the present time we consider the value found when 1,000 parts per million of sludge is present as the Nordell Index.

Acknowledgment

The writers wish to acknowledge and express their appreciation for the valuable services rendered by Mr. Philip F. Morgan, M. S., Research Fellow in Hydraulic and Sanitary Engineering, University of Wisconsin, who assisted the writers and devoted much of his time for eighteen months to the development of the technique and experimental investigation outlined in this paper. They further wish to acknowledge the assistance of Messrs. W. E. Trukenbrod and Adolph Wandfluh, Chairman, Disposal Plant Committee, and Operator, Monroe Sewage Works.

The experimental investigation conducted by the senior author at locations indicated in tables VIII to XVIII inclusive was made possible by a grant from the Wisconsin Alumni Research Foundation (**34**: 42, 15–B) and the accompanying leave of absence granted the senior author by the University Board of Regents. The writers wish to acknowledge the cooperation and assistance of the following men, for without their help, the investigation could not have been completed:

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A COMPARISON OF PERMANGANATE OXYGEN DEMAND, B.O.D. AND DIRECT ABSORPTION OF OXYGEN

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During the course of investigations on various distillery wastes which are being carried out in this laboratory it has been observed repeatedly that the results of the biochemical oxygen demand test on such wastes consistently run much lower than the results of the permanganate oxygen consumed test. Most wastes present a situation just the reverse of this. These apparently anomalous results, coupled with the recent appearance in the field of sewage work of the Nordell machine for direct determination of oxygen absorbed by sewage, prompted this laboratory to undertake an investigation of the various oxygen absorption tests.

The work was arranged to include, also, a comparison of the results obtained from the permanganate oxygen consumed test where N/80 $KMnO_4$ was used as the reagent, with those obtained where N/8 $KMnO_4$ was used. The former is the solution recommended by Standard Methods of Water Analysis [1] while the latter is the solution recommended years ago by various British workers.[2] This phase of the problem grew out of the fact that investigators have reported that the use of stronger solutions of permanganate gives results more nearly comparable to the biochemical oxygen demand when the tests are applied to heavily contaminated materials such as industrial wastes.[3] The British reagent was considered the logical "strong" solution to utilize in the comparison, because by dilution 1–10 the Standard Methods permanganate could be prepared from the stronger material. Thus the N/8 reagent was more convenient to use than others suggested as, for example, the .1N solution proposed by Hoover.[3]

Experimental Procedure

The problem under investigation naturally resolved itself into three phases: (1) A comparison of N/80 and N/8 $KMnO_4$ solutions; (2) A comparison of the results obtained in the permanganate oxygen consumed determination, using both $KMnO_4$ reagents, and those obtained in the biochemical oxygen demand test; (3) A comparison between permanganate oxygen consumed, B.O.D., and the results obtained with the direct absorption apparatus. The materials used in these experiments included: wastes from two distilleries, one producing ethyl alcohol, the other, butyl alcohol and acetone; anaerobically digested wastes from these distilleries; and raw domestic sewage.

Comparison of Permanganate Solutions

The results of this comparison are shown in Table I. The N/80 $KMnO_4$ was applied as directed in Standard Methods.[1] The N/8 $KMnO_4$ was applied in the same fashion but utilized solutions of permanganate

Table I

Sample	Oxygen Consumed N/80 $KMnO_4$, p.p.m.	Oxygen Consumed N/8 $KMnO_4$, p.p.m.
Raw butyl alcohol waste	4,000	6,000
Raw butyl alcohol waste	4,000	6,300
Raw ethyl alcohol waste	8,000	14,000
Raw ethyl alcohol waste	9,200	14,000
Digested ethyl alcohol waste	1,300	1,850
Digested ethyl alcohol waste	1,425	1,900
Raw domestic sewage	110	165
Raw domestic sewage	150	200
Raw domestic sewage	80	180
Raw domestic sewage	125	150
Raw domestic sewage	50	100
Pure glucose *	5,200	7,200

* Calculated for complete oxidation—10,000 p.p.m. O_2 required.

and oxalate ten times as strong as the Standard Methods reagents. The H_2SO_4 recommended by Standard Methods was used in both tests. As a control procedure, a solution of glucose was made up in such strength as to require 5 cc. of the strong reagent in 1–200 dilution, and 5 cc. of the Standard Methods permanganate in 1–2000 dilution for complete oxidation of the glucose, or 10,000 p.p.m. permanganate oxygen consumed in both cases.

The data in Table I show that in all cases the N/8 reagent gave higher results than the standard reagent. Agreement between the two was closest in the case of digested wastes and raw domestic sewage. Results on the glucose solution seem to indicate that the N/8 reagent will give values more nearly representative of complete oxidation while the N/80 reagent will give results more nearly comparable to a five day B.O.D. which is normally about 68 per cent of the total first-stage B.O.D.[4] As will be noted below, these conclusions, which apparently apply to pure carbonaceous materials of the type of dextrose, also apply to some types of waste but do not apply to others.

Comparison of Permanganate Oxygen Consumed with B.O.D. Results

The data on this phase of the problem appear in Table II. Both permanganate reagents were used in order that some idea might be

TABLE II

Sample	Oxygen Consumed N/80 $KMnO_4$ p.p.m.	Oxygen Consumed N/8 $KMnO_4$ p.p.m.	5-Day B.O.D. p.p.m.
Raw butyl alcohol waste	4,000	6,000	4,920
Raw butyl alcohol waste	4,000	6,300	4,200
Raw butyl alcohol waste	22,000		13,500
Raw butyl alcohol waste	21,600		16,950
Raw butyl alcohol waste	25,000		14,000
Raw butyl alcohol waste		17,640	3,274
Raw butyl alcohol waste		11,600	4,920
Raw butyl alcohol waste		8,000	3,900
Raw ethyl alcohol waste	9,200	14,000	14,900
Raw ethyl alcohol waste	16,800		20,275
Raw ethyl alcohol waste	18,200		22,050
Raw ethyl alcohol waste	10,000		11,000
Raw ethyl alcohol waste	12,350		15,800
Raw ethyl alcohol waste		14,900	12,350
Raw ethyl alcohol waste		14,000	14,900
Raw ethyl alcohol waste		15,800	16,500
Digested ethyl alcohol waste	780		293
Digested ethyl alcohol waste	960		684
Digested ethyl alcohol waste	1,860		796
Digested ethyl alcohol waste	3,800		1,031
Digested ethyl alcohol waste	2,000		845
Digested ethyl alcohol waste		2,600	1,300
Digested ethyl alcohol waste		2,100	1,063
Digested ethyl alcohol waste		2,600	750
Digested ethyl alcohol waste		2,100	1,640
Digested ethyl alcohol waste	1,300	1,850	1,204
Digested ethyl alcohol waste	1,425	1,900	1,190
Domestic sewage	110	165	370
Domestic sewage	80	180	247
Domestic sewage	125	150	187
Domestic sewage	50	100	157
Pure Glucose	5,200	7,200	4,611

obtained as to which reagent offered results more comparable to the conventional five day B.O.D. Biochemical oxygen demand tests were made by the dilution method according to the procedure recommended by Standard Methods.[5]

It may be seen from the table that in many of the cases investigated, the five-day B.O.D. ran somewhat lower than the oxygen consumed values given by either permanganate reagent, though exceptions appear. From the data obtained it would seem that the Standard Methods permanganate gives results more nearly comparable to the five-day

B.O.D. when the tests are applied to raw butyl alcohol waste or to digested ethyl alcohol waste. Agreement between the tests is, however, very poor at best. When applied to raw ethyl alcohol waste the N/8 $KMnO_4$ seems, in general, to give results more closely corresponding to the five-day B.O.D., with much better agreement between the tests than noted directly above. Domestic sewage presents a picture somewhat more familiar than that shown by the trade wastes. The B.O.D. on the domestic sewage ran consistently higher than the permanganate oxygen consumed values, rather than generally lower as in the case of the trade wastes. The N/8 $KMnO_4$, since it gives higher values than the N/80 $KMnO_4$, gives results more nearly comparable to the five-day B.O.D. The data show, further, that wastes which have been subjected to anaerobic digestion give, in most cases, B O D. results which are lower than oxygen consumed values obtained by either permanganate reagent. The same is true for raw butyl alcohol waste. Raw ethyl alcohol waste, however, gives B.O.D. results which are generally higher than oxygen consumed values given by the Standard Methods permanganate but which are quite comparable to values given by the N/8 reagent.

The five-day B.O.D. on pure glucose was close to the oxygen consumed value given by the N/80 permanganate, confirming the conclusion above that the Standard Methods permanganate is, perhaps, a better criterion of the five-day B.O.D., while the stronger permanganate gives results more closely comparable to complete oxidation.

The tests as applied to raw ethyl alcohol waste and domestic sewage seem to confirm the results obtained by Hoover who states: "As a result of a large number of comparisons of results of different methods of determining the important oxygen-consumed values of industrial wastes, a procedure involving the use of more concentrated solutions of reagents than those recommended in the 'Standard Methods for the Examination of Water and Sewage' has been found to give results more nearly in agreement with the values obtained for the content of oxygen-consuming material by the standard biochemical oxygen demand test." [3] When the tests are applied to raw butyl alcohol waste, anaerobically digested materials, and pure compounds the results do not substantiate Hoover's conclusions.

In an attempt to formulate some explanation for the repeated occurrence of B.O.D.'s lower than oxygen consumed values, three, five, and ten-day B.O.D.'s were run on raw butyl alcohol slop and on digested ethyl alcohol waste, to see whether there was any evidence of a lag phase in bacterial action. The results of these tests are shown in Table III. Calculations of theoretical B.O.D. are based on the stability table in Standard Methods.[4] The data indicate that there is a lag in bacterial activity. Theoretical ten-day B.O.D.'s calculated from the observed

TABLE III

Sample	3-day B.O.D. p.p.m.	5-day B.O.D. p.p.m.	10-day B.O.D. p.p.m.	Theoretical 5-day B.O.D. Calculated from Observed 3-day B.O.D. p.p.m.	Theoretical 10-day B.O.D. Calculated from Observed 3-day B.O.D. p.p.m.	Theoretical 10-day B.O.D. Calculated from Observed 5-day B.O.D. p.p.m.
Raw butyl alcohol waste	4,390	6,183	9,367	5,970	7,902	8,183
Digested ethyl alcohol waste	600	815	2,618	816	1,080	1,079

three-day and five-day B.O.D.'s are lower than the observed ten-day B.O.D. in both cases. The theoretical five-day B.O.D. calculated from the observed three-day B.O.D. is lower than the observed five-day in the case of the raw butyl alcohol waste but these two values check on the sample of digested ethyl alcohol waste. These data show that bacterial activity was slow at the start but speeded up toward the end of the ten-day period. On the raw butyl alcohol waste, the lag phase is not so pronounced and apparently doesn't last as long as in the case of the digested waste. The latter material shows a continuation of the lag or slow bacterial activity at least to five days because the theoretical five-day B.O.D. calculated from the observed three-day B.O.D. closely checked the observed five-day value. The observed ten-day B.O.D. was much higher than the calculated. These bacterial lags possibly offer a partial explanation for the low B.O.D. values on these two types of waste.

COMPARISON OF PERMANGANATE OXYGEN CONSUMED, B.O.D. AND DIRECT ABSORPTION

Results obtained from this phase of the investigation are presented in Table IV. The oxygen consumed and B.O.D. tests were carried out as above. The apparatus used for the direct absorption determinations is the Nordell apparatus recently developed by C. H. Nordell of the Advance Engineering Company, Chicago. This device is described in the diagram presented in Figure 1 and pictured in Figures 2 and 3. Instructions for using the machine and for calculating the Nordell numbers (p.p.m. per hour of oxygen absorbed) accompany the diagram. The machine was developed primarily for determining the efficiency of mixtures of activated sludge and raw sewage but we have, in this laboratory, tried to adapt it to the determination of B.O.D. to effect a saving in time and to reduce the cumbersomeness of the dilution method.

TABLE IV

Sample	Oxygen Consumed N/80 $KMnO_4$ p.p.m.	Oxygen Consumed N/8 $KMnO_4$ p.p.m.	Dilution Method 5-day B.O.D. p.p.m.	Direct Absorption 5-day B.O.D. p.p.m.
Digested ethyl alcohol waste	1,300	1,850	1,204	1,677
Digested ethyl alcohol waste	1,425	1,900	1,190	1,127
Domestic sewage	110	165	370	475
Domestic sewage	80	180	247	428
Domestic sewage	125	150	187	440
Domestic sewage	50	100	133	360 [a] 163 [b]

[a] Calculated on the assumption that the "Nordell constant" values are valid for five days.

[b] Calculated to the second rise on the curve (nitrification stage).

In our experiments, four liters of the sample were placed in the machine and the aerating wheel set in motion. The rate of oxygen absorption per minute was determined at the start of the run by taking a series of from two to five readings as described in Figure 1 and averaging these values. Temperature corrections were applied as per instructions. Each hour thereafter readings were taken until the values became constant. These readings, which represent the rate of oxygen absorption per minute, were translated into Nordell numbers (p.p.m. of oxygen absorbed per hour) by the method given in the description. The Nordell numbers at the beginning and at the end of each hour were added and divided by two to obtain the average p.p.m. of oxygen absorbed during that hour. These values were then added and, on the assumption that the readings, after once becoming constant remained so, calculated to 120 hours (five days). These average values, representing the p.p.m. of oxygen absorbed during each hour, are plotted against time in hours in the curves shown in Figures 4, 5, and 6.

Operating Instructions

To determine rates of oxygen absorption of various liquids by "Odeeometer" instructions are as follows:

1. Remove front and rear shell of carrying case.
2. Remove "Tube Panel" from holder in rear of carrying case. Blow out all pipe lines, using "bulb" on rear of "Center Panel," to be sure there is no stoppage in the lines. Place panel in position as shown above. Then, using wrench, connections are made to top of connecting tees on rear of center panel and should be drawn tight to prevent air leakage.

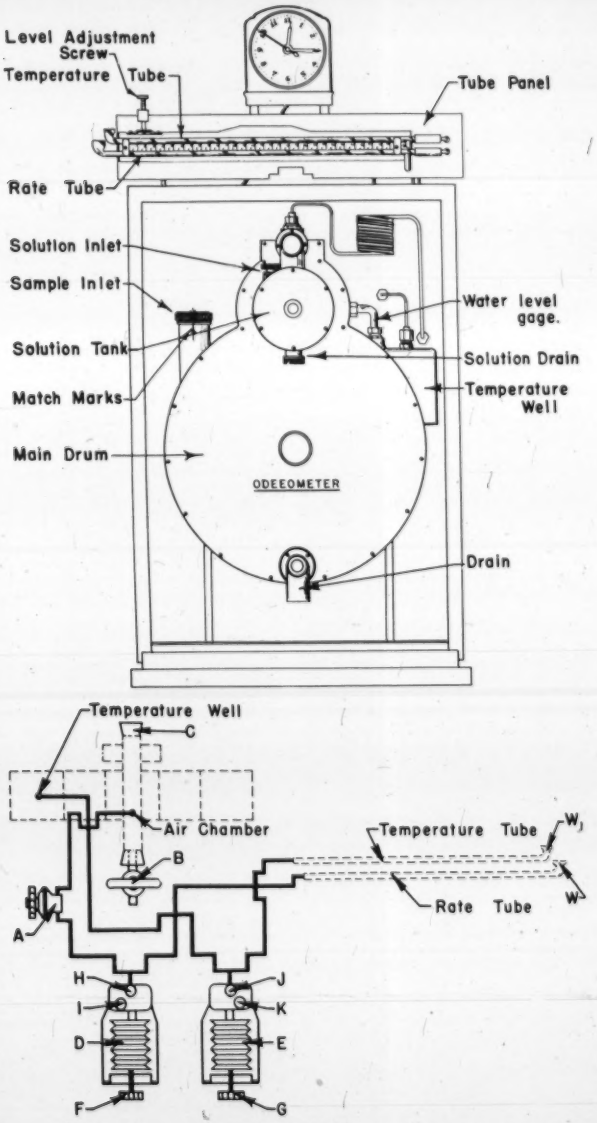

FIG. 1.—Diagram of Nordell Oxygen Demand Apparatus.

3. Sample to be tested should contain 4000 cubic centimeters. Pour this in "Main Drum" through "Sample Inlet." Then replace plug and draw up tightly until "match marks" are in line. Then through "Solution Inlet" place thirty cubic centimeters of 10 per cent solution of sodium hydroxide (NaOH) which has been allowed to come to room temperature. Start motor with switch on back panel. Have valve "*B*" open and rubber plug "*C*" out to permit aeration of sample.

4. Then to insert bubble fluid in Rate tube, have valves "*A*" and "*B*" open. Squeeze 4 or 5 drops from eyedropper into Well "*W*." Run back and forth to wet

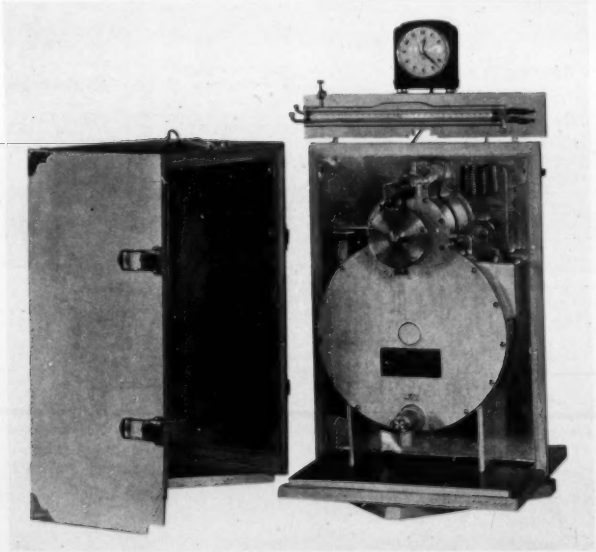

FIG. 2.—Photograph of Nordell Oxygen Demand Apparatus, front view.

with oil as in directions for setting bubble in paragraph "5." Then level tube by using level adjustment screw.

5. To set bubble on an even division preparatory to a determination, close valve "*A*," open screw "*H*" and by using adjustment screw "*F*" bubble may be moved forward or backward to position. Then close screw "*H*." Screws "*H*" and "*I*" designate valves, "*H*" cuts bellows "*D*" off from rate tube line. "*I*" opens to atmosphere to permit refilling of bellows with air when required.

6. To insert bubble in temperature tube, open screws "*J*" and "*K*," then close "*J*," add drops to well "*Wl*." Adjust bubble to position using adjustment screw "*G*." Then close valve "*K*." Screws "*J*" and "*K*" designate valves, "*J*" cuts bellows "*E*" off from temperature tube line. "*K*" opens to atmosphere to permit refilling of bellows with air when required.

7. The *Rate* of oxygen absorption is the distance of bubble travel in centimeters over a one-minute period, multiplied by the tube constant as shown on well "*W*" of rate tube. The product of these two figures is parts per million per hour of oxygen absorption; *i.e.*, if bubble travels 12 centimeters in one minute and the constant as shown on well in rate tube is 2.1, then $12 \times 2.1 = 25.2$ parts per million per hour of oxygen absorption.

8. To obtain the *Rate* of oxygen absorption, insert rubber plug "*C*" in place, open valve "*A*," then close valve "*B*," observing the time at which valve "*B*" is closed. When time period of determination is complete, snap shut valve "*A*" and reading may

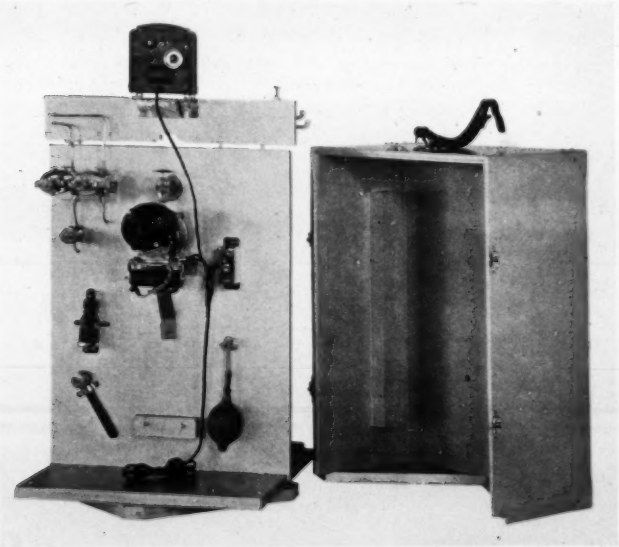

FIG. 3.—Photograph of Nordell Oxygen Demand Apparatus, rear view.

then be made at leisure. Then remove rubber cork "*C*," open valve "*B*" to atmosphere to further aerate sample.

9. To correct for a change in temperature in Main Drum, set bubble in temperature tube on an even division preferably at 5 or 6 centimeters to allow for either expansion or contraction in volume in Main Drum. If during time period of observation for oxygen absorption rate, temperature bubble moves outward, the total distance of travel should be added to the distance of bubble travel in rate tube; *i.e.*, if rate bubble moves inward 12 centimeters in 1 minute and temperature bubble moves outward 1 centimeter during the minute interval of reading, the actual reading becomes $12 + 1 = 13$ centimeters. If temperature bubble moves inward, the distance of travel in centimeters,

should be deducted from distance of bubble travel in rate tube; *i.e.*, if rate bubble moves inward 12 centimeters in 1 minute and temperature bubble moves inward 1 centimeter during the minute interval of reading, the actual reading becomes 12 − 1 = 11 centimeters.

10. After completing observations on a sample, the interior of the Main Drum should be thoroughly cleaned periodically. Also, sodium hydroxide solution should be drained from the solution tank and tank rinsed out.

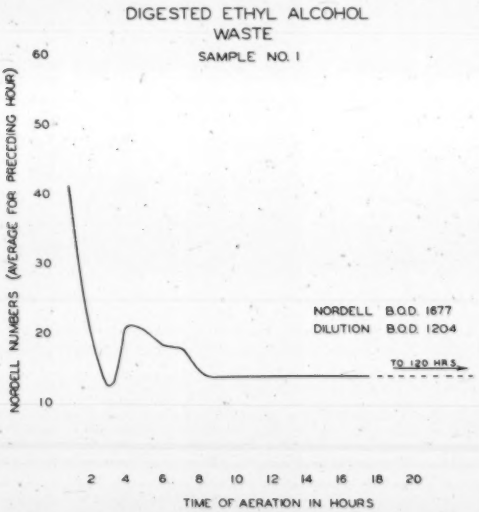

FIG. 4.—Curve showing rate of oxygen demand of digested ethyl alcohol waste by Nordell Apparatus.

The data obtained with the Nordell machine are presented along with comparisons with B.O.D. and oxygen consumed values in Table IV. The above method of calculation gave results quite comparable to the five-day B.O.D. obtained by the dilution method, where digested ethyl alcohol waste was used. The results on domestic sewage given by the Nordell apparatus and calculated as above were, however, considerably higher than the five-day B.O.D. values obtained by the dilution method. In an attempt to devise a successful method of calculation for wastes of this type, the machine was allowed to run beyond the constant reading point. During the third day, a second rise in the readings was noted (see curve Fig. 6). This rise was accompanied by an increase in nitrites

from almost nil to a value of 2.5 p.p.m. leading us to believe that this second rise marked the beginning of the nitrification stage. The calculations were carried only to the beginning of this nitrification stage and the values were found to be quite comparable to the five-day B.O.D. (See last sample, Table IV and Curve Fig. 6.)

As yet, these calculations are entirely empirical but we hope, by further researches on this problem, to discover a relationship between the biochemical oxygen demand as obtained by the dilution method,

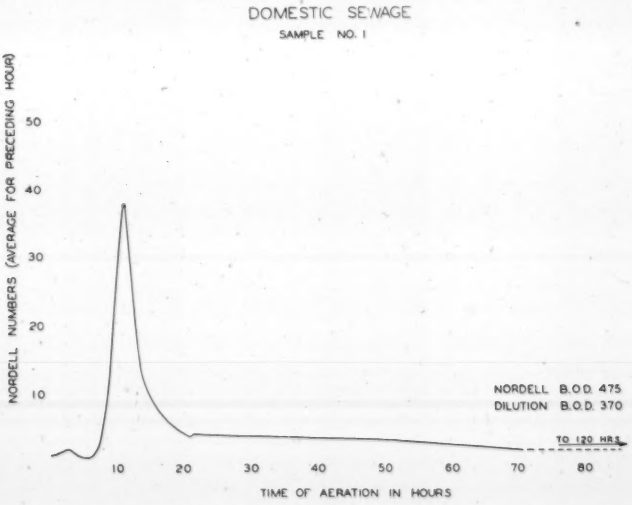

FIG. 5.—Curve showing rate of oxygen demand of domestic sewage by Nordell Apparatus.

and the direct absorption as determined from the Nordell number, which will allow the development of a formula for calculation of results which will be applicable to all types of waste.

Probably the first attempt to apply direct absorption methods to the determination of the oxygen demand of sewage was that of Adeney [6] which was later revived by Sierp.[7] This method was criticized by several investigators. Rideal and Burgess [8] found the apparatus unsatisfactory due to leakage. Sand and Troutman [9] believed that the amount of agitation given a sample is an important factor that should not be overlooked. Calvert [10] stated that comparative tests showed that the

direct absorption method yielded divergent results. Symons and Buswell,[11] however, compared Sierp's method with the dilution method for the determination of B.O.D. and found little difference in the results as obtained by the two methods.

The Nordell direct absorption method is believed by the authors to have possibilities in the determination of B.O.D. and to have the following advantages over the dilution method:

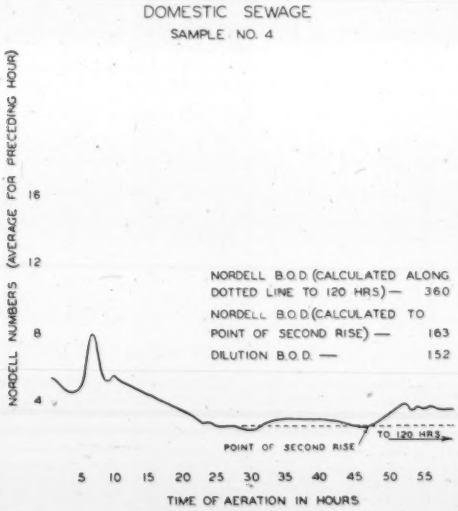
DOMESTIC SEWAGE
SAMPLE NO. 4
NORDELL NUMBERS (AVERAGE FOR PRECEDING HOUR)
16
12
8
4
NORDELL B.O.D (CALCULATED ALONG DOTTED LINE TO 120 HRS)— 360
NORDELL B.O.D (CALCULATED TO POINT OF SECOND RISE) — 163
DILUTION B.O.D. — 152
POINT OF SECOND RISE
TO 120 HRS
5 10 15 20 25 30 35 40 45 50 55
TIME OF AERATION IN HOURS

FIG. 6.—Curve showing rate of oxygen demand of domestic sewage by Nordell Apparatus, extended to show start of secondary stage.

1. The course of the curve is always apparent.
2. A shorter time is required to obtain results.
3. No dilution is required. B.O.D.'s obtained by the Standard Methods procedure on samples requiring high dilutions are known to be of questionable accuracy.
4. The Nordell method will be adaptable to field work as no reagents are required.
5. The rate of oxygen absorption is as important as the total amount absorbed.

The authors wish to acknowledge the valuable assistance of C. H.

Nordell, C. S. Boruff, and H. R. Styles in obtaining materials used in this investigation.

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ACTIVATED CARBON IN SEWAGE TREATMENT *

By Willem Rudolfs and E. H. Trubnick

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The possibility of using activated carbon as an aid in sewage treatment has been attractive for a number of years. A search of the literature has not disclosed any references and therefore it was thought of interest to survey the field. Based upon water treatment experience the control of odors was one of the first considerations. The possibility of using activated carbon for improving poorly working or overloaded plants was considered of equal or greater importance.

Through the establishment of a fellowship by the Industrial Chemical Sales Corporation, funds and material were made available for the study. The work here reported may be divided into (1) laboratory and (2) field experiments.

Laboratory Experiments

The laboratory survey dealt principally with the effect of activated carbon on reaction control, carbon dioxide absorption, reduction of suspended solids, turbidity and B.O.D., clarification of supernatant, settling and dewatering of activated sludge, sludge digestion, removal of organic matter and B.O.D. from trickling filter effluent, hydrogen sulphide production, and effect when used in combination with coagulants and chlorine. An attempt was also made to find a method to evaluate different activated carbons on the market. The scope of these investigations was limited to a preliminary survey and no attempt was made to investigate exhaustively any phase of the work.

It may not be amiss at this place to say a few words about the manufacture of activated carbon and theories of adsorption by activated carbon.

Mantell (11) divided the vegetable decolorizing carbons into several classes, according to the method of manufacture.

1. Carbonizable vegetable materials such as sawdust, peat, seaweed, molasses, etc. may be mixed with porous inorganic substances such as pumice stone or infusorial earth. The mixture is strongly heated, whereupon the carbon in the vegetable matter is deposited throughout the porous base.

2. Carbon may be deposited on an inorganic base which is afterwards separated from the carbon by chemical means. Vegetable materials are

* Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J. Department Water and Sewage Research.

mixed with chemical reagents such as lime, chalk, sulphuric acid, calcium chloride, zinc chloride, phosphoric acid, etc.; and after carbonization the inorganic matter is dissolved out, leaving the resulting carbon. The zinc chloride, phosphoric acid, etc., function as activating agents. The presence of the inorganic substances during carbonization prevents the formation of adsorbed films of the inactive material which would cover the surface of the active carbon, as occurs when the vegetable materials are carbonized alone.

3. Materials such as lignite, waste pulp liquors, sawdust, etc., may be carbonized in retorts under controlled conditions of temperature and atmosphere. After preparation the carbon is "activated" by air, oxides of carbon, chlorine, superheated steam, or mixtures of steam and air.

Practically all active carbons that are used to any material extent come under the third classification. All materials in this class require activation to produce a carbon of high adsorptive capacity.

In regard to the theory of adsorption by activated carbon Chaney (6) states that active and inactive carbons differ in two important characteristics: (1) the temperature of formation, and (2) the chemical activity, or susceptibility to oxidation. He says that the active modification is formed whenever carbon is deposited at a relatively low temperature (in general, below 600–700° C.). The inactive carbon is formed from similar decomposition, generally at temperatures above 600–700° C. However, he points out that at the lower temperatures hydrocarbons originating from the vegetable materials are formed and are held on the surface of the carbon. If this is the case, then activation consists in removing the adsorbed hydrocarbons from the surface.

Brender and Brandis (5), five years after Chaney's work, supplied confirmatory evidence of the adsorption of hydrocarbons at the lower temperatures of carbonization.

Ruff (13) holds the view that the centers of adsorption of a carbon are unsaturated, unoriented atoms or atomic complexes which are present in all amorphous carbons together with saturated atoms and mineral residue. Whenever these unsaturated atoms are present on the surface, the carbon is active. Such unsaturated atoms may be covered by a thin film of saturated carbon, in which case the observed adsorption is explained by Ruff on the basis of Eucken and Polanyi's (7) theory. In the case of adsorption directly on the unsaturated groups, Ruff interprets the phenomenon in accordance with Langmuir's (10) theory.

Berl (3) and co-workers have made x-ray diagrams of a number of active carbons. These diagrams give no indication of the presence of amorphous carbon. Berl therefore says that the activity cannot be ascribed to the presence of amorphous carbon, but probably depends on both the development of the carbon surface and on the presence of discontinuities or active centers.

Effect on pH Value, Carbon Dioxide and Acids

I. Effect on pH Value.—(*a*) Various quantities of powdered activated carbon varying from 5 to 5000 ppm. were added to 100 cc. samples of raw settled sewage, the mixture allowed to stand for 15 minutes, filtered and pH determinations made on the filtrate.

(*b*) One-half gram of carbon was added to 250 cc. of each of three different sewages; samples were settled and filtered and pH determinations made.

This procedure was repeated with samples of the same sewages which had previously been boiled to drive off any CO_2 and volatile acids. The results are shown in Table I.

Table I.—*Effect of Activated Carbon on pH of Sewage*

(*a*) *Effect of Carbon Dosage*

Carbon Dosage P.p.m.	pH
0	7.2
5	7.35
15	7.4
25	7.4
50	7.45
100	7.5
5000	7.9

(*b*) *Effect of Carbon on pH of Boiled Sewage*

	Unboiled		Boiled	
	No Carbon pH	With Carbon pH	No Carbon pH	With Carbon pH
Sample 1	6.8	7.0	9.1	9.1
" 2	6.8	7.3	9.2	9.2
" 3	7.5	7.7	9.1	9.1

It is evident that activated carbon raised the pH of sewage; and that the rise in pH varied directly with the amount of carbon added. The activated carbon had no effect on the pH of boiled sewage, in which all CO_2 and volatile acids had been driven off.

These results indicate that the rise in pH of sewage effected by the activated carbon may be due to the adsorption of CO_2 or of volatile acids, or of both.

II. Adsorption of Carbon Dioxide from Solution. (*a*) *Rate of Adsorption. Method.*—(1) Two-gram portions of powdered activated carbon were added to each of a number of 1-liter aliquot portions of a solution of

CO_2, which was prepared by bubbling the gas through tap water and diluting with tap water until the solution contained approximately 30 p.p.m. dissolved CO_2.

After various contact times ranging from a half minute to 30 minutes, the carbon was filtered out of the solution through paper. The carbon dioxide content of the filtrates was determined in accordance with "Standard Methods of Water Analysis" (1). For control a portion of the solution was treated in exactly the same manner, except for the addition of carbon.

(2) This procedure was repeated with a smaller portion (10 p.p.m.) of activated carbon.

Results.—(1) As seen from Figure 1, it is evident that with 2 grams of

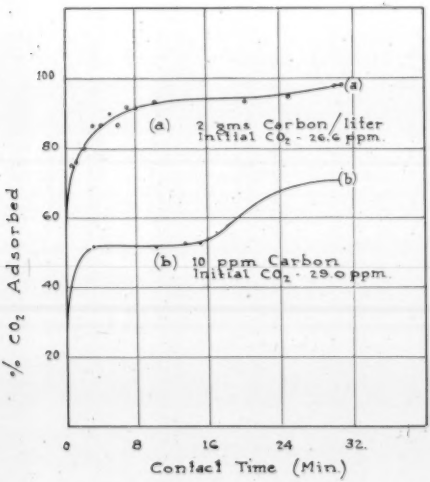

FIG. 1.—Rate of adsorption of CO_2 by activated carbon.

carbon per liter of CO_2 solution, 75 per cent of the original 26.6 p.p.m. CO_2 was removed within a half minute. In 30 minutes, 98 per cent or 26.2 p.p.m. of the CO_2 was removed from solution. There was no further removal after 30 minutes.

(2) Using 10 p.p.m activated carbon, 40 per cent of the original 29 p.p.m. dissolved CO_2 was removed within a half minute, after which time there was very little further removal until after 15 minutes had

elapsed. At that time the rate of removal increased, until, after 30 minutes, 70 per cent or 20.5 p.p.m. of the CO_2 was removed from solution.

The concentration of CO_2 chosen for this work, although considerably higher than that usually found in water, is within the limit of solubility of the gas in water.

Carbon dosages of this magnitude are excessive in water or sewage treatment, from a practical standpoint. However, these results are of interest, as no work appears to have been reported on the adsorption of carbon dioxide from solution.

With 10 p.p.m. of activated carbon, the removal of CO_2 was much slower. The retardation after 2 minutes, and subsequent resumption after 15 minutes, may very possibly be due to the fact that not all the carbon dioxide was present as such. A portion of the CO_2 was present as bicarbonates, as a result of the presence in the water of alkaline substances, and it is likely that not until the last of the free CO_2 had been adsorbed did the carbon have any effect on the bicarbonates.

Marein (12) points out that sodium bicarbonate is adsorbed by activated carbon. In fact he has attempted to evaluate activated carbons by determining their bicarbonate adsorption.

(*b*) *Effect of Carbon Dosage. Method.*—(1) To each of seven 1-liter aliquot portions of a solution of approximately 30 p.p.m. carbon dioxide in tap water, was added powdered activated carbon in amounts varying from 0.1 gm. to 2 gms., left in contact for 15 minutes, filtered and the CO_2 content of the filtrates determined.

(2) This procedure was repeated, with smaller dosages of carbon. The doses varied from 5 to 100 p.p.m. added as a water suspension.

Results.—(1) In the higher range, 100 p.p.m. of carbon removed 45 to 50 per cent of the CO_2 in fifteen minutes; approximately 70 per cent removal was obtained with 250 p.p.m. of carbon. Increased carbon doses gave no further removal until more than 1000 p.p.m. had been added. The results are shown in Figure 2.

(2) In the lower range, 5 p.p.m. of carbon removed approximately 35 per cent of the CO_2 in fifteen minutes. The removal of CO_2 increased slowly with increased carbon dosage until, with 1000 p.p.m. of carbon about 55 per cent of the carbon dioxide was removed (Fig. 3).

It is evident that it was comparatively easy to remove the first 70 per cent of the CO_2, but that a considerable excess of carbon was necessary in order to effect any further removal.

(*3*) *Rate of Reduction of Acidity in Sewage. Method.*—10 p.p.m. of powdered activated carbon, in water suspension, was added to 5 liters of sewage which contained 55.5 p.p.m. total acidity (calculated as $CaCO_3$). At various intervals, ranging from a half minute to 30 minutes, aliquot portions of the sewage were filtered to remove the carbon, and the total

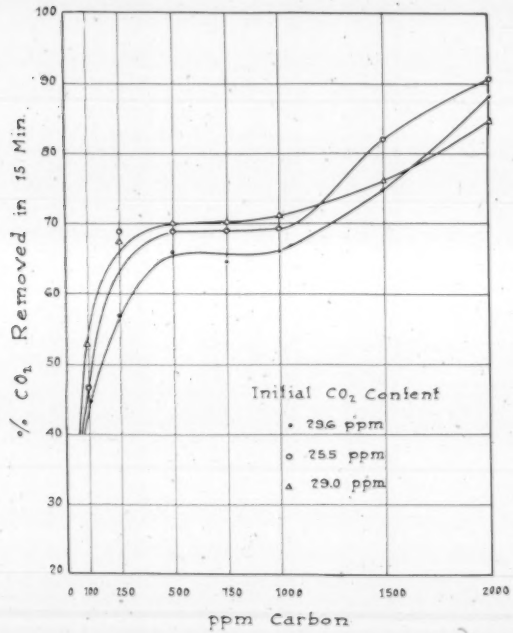

FIG. 2.—Effect of carbon dosage on CO_2 adsorption (large doses).

acidity of the filtrates was determined by titration with N/50 NaOH to the phenolphthalein end-point.

Results.—As seen from Figure 4, within one minute the total acidity of the sewage was reduced by 17.5 p.p.m. or 31.5 per cent. After one minute, no further reduction was evidenced. A boiled sample of the sewage reacted alkaline to phenolphthalein, indicating that all the acidity was due to carbon dioxide and volatile acids.

It appears that whatever acid substances were removed from the sewage by the carbon consisted of carbon dioxide or volatile acids, or both.

Considering the many substances present in sewage, it is entirely conceivable that in one minute a protective film of adsorbed substances formed on the surface of the carbon particles, preventing any further removal of the acid substances.

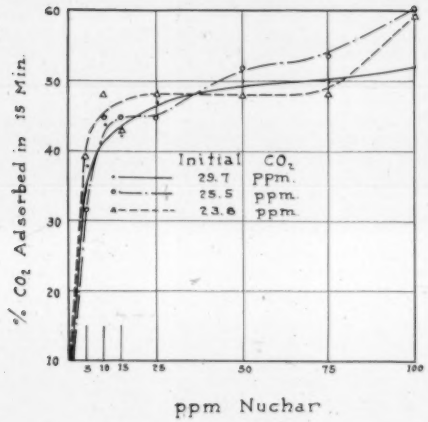

FIG. 3.—Effect of carbon dosage on CO_2 adsorption (small doses).

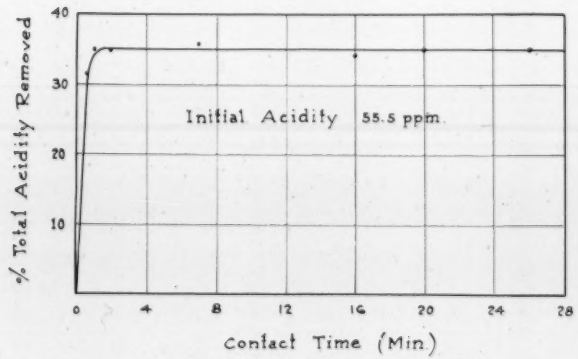

FIG. 4.—Rate of reduction of acidity by 10 p.p.m. activated carbon.

(4) *Adsorption of Butyric Acid. Method.*—Seven 500-cc. solutions of butyric acid, varying in concentration from approximately 10 to 1000 p.p.m., were treated with powdered activated carbon, with approximately one part of carbon to one part of acid. The mixtures were allowed to stand for twenty-four hours, after which time they were filtered through

paper. This procedure was repeated with duplicate solutions of butyric acid without carbon. The butyric acid content of the filtrates was determined by titration with N/50 NaOH to the phenolphthalein end-point. The results are shown in Table II.

TABLE II.—*Adsorption of Butyric Acid by Activated Carbon*

Initial Butyric Acid Concentration P.p.m.	Carbon P.p.m.	Butyric P.p.m.	Acid, Per Cent of Initial	Adsorbed Mgs./Gm. Carbon
1028	1000	151	14.7	151
520	500	70	13.5	140
259	250	45	17.4	180
105	100	10	9.5	100
53.8	50	6.6	12.3	132
27.9	25	3.3	11.8	132
12.1	10	0.8	6.6	80

Results.—When the initial butyric acid concentration and the amount of carbon increased, the actual amount of acid adsorbed increased. However, no constant or proportional trend was noted when the results were calculated either as per cent of initial butyric acid adsorbed, or the amount of acid adsorbed per gram of carbon.

Apparently the experimental error in this experiment was very great, but the results show that the carbon adsorbed butyric acid.

The volatile fatty acids found in sewage are mainly of higher order in the homologous series than butyric. Freundlich (8) has pointed out that fatty acids are adsorbed at an increasing rate directly as the number of carbon atoms is increased. It is possible therefore that acidity reduction in sewage with activated carbon may be partly due to the adsorption of fatty acids, as well as of carbon dioxide.

FLOCCULATION OF SEWAGE SOLIDS WITH ACTIVATED CARBON

Method.—(1) Ten to 20 p.p.m. portions of powdered activated carbon were added to 1.5 liter portions of raw sewage, stirred at the rate of 15 r.p.m., and settled for a half hour.

This procedure was repeated with, in addition to the carbon treatment, addition of 10 p.p.m. of ferric iron as $FeCl_3$. This quantity of iron was much smaller than the optimum for complete coagulation. By adding less iron than was necessary, it was hoped to determine whether the activated carbon might be an aid in chemical treatment.

Determinations were made of the amount of sludge settled in a half-hour, the oxygen-consumed values and turbidity of the supernatant liquor of each sample.

(2) Ten to 100 p.p.m. portions of activated carbon were added to 100 cc. samples of sewage, which were then allowed to stand for one hour. The five-day B.O.D. of the samples was determined.

Results.—No evidence was noted of flocculation or purification of raw sewage by activated carbon, as measured by the amount of sludge settled from a treated sample, the five-day B.O.D., or the oxygen-consumed values.

Used in conjunction with partial iron treatment, the activated carbon effected no further clarification or purification than was obtained with the iron treatment alone.

Effect of Activated Carbon on B.O.D. of Effluent of Chemically Treated Sewage

Method.—The effluent from an experimental plant treating sewage partially flocculated with $FeCl_3$ was obtained and to one-liter aliquot portions 0, 5, 10, 15, 20 and 25 p.p.m. activated carbon was added. The samples were stirred at 18 r.p.m. for 20 minutes, settled for 2 hours and the B.O.D. of the supernatant liquor determined; on other portions, similarly treated, the B.O.D. was determined before and after filtration through filter paper. The results of two trials are shown in Table III.

Table III.—*Effect of Carbon on Chemical Effluent*

Carbon Added	B.O.D.			
	Unfiltered		Filtered	
	P.p.m.	% Red.	P.p.m.	% Red.
0	104	—	63.3	—
5	98	6	50.8	19.7
10	82	21.2	45.0	28.9
15	100	4.0	46.0	27.4
20	84	19.2	47.1	25.6
25	85	18.3	42.8	32.4

Without filtering the effluent a maximum B.O.D. reduction of about 20 per cent was obtained with 10 p.p.m. activated carbon and with filtering, from 20 to 30 per cent, with varying quantities of carbon. Apparently the activated carbon acted on the dissolved material because the p.p.m. reduction of B.O.D. was practically constant whether most of the suspended material was filtered out or not.

Effect of Activated Carbon on Bactericidal Action of Chlorine

Method.—(1) To 100-c.c. samples of settled, cotton-filtered sewage, chlorine solution was added to satisfy 50 and 100 per cent of the chlorine demand and 30 minutes contact allowed. Residual chlorine was removed with sodium thiosulphate. This procedure was repeated with chlorine solution to which powdered activated carbon had been added. The diluted samples were plated on nutrient agar, incubated at 20° C. for 48 hours, and total bacterial counts determined.

(2) To one of two aliquot portions of a chlorine solution containing 354 p.p.m. available Cl_2, was added 350 p.p.m. powdered activated carbon; the other portion of the Cl_2 solution was used as a control. After standing for a half hour, the two samples were filtered through paper, and determinations were made of available chlorine, chlorides, and pH.

Results.—The results in Table IV show that activated carbon reduced the kill effected by chlorine. No quantitative relation was established between the amount of carbon added and the extent of the reduction of kill.

Upon standing overnight, some or all of the chlorine in contact with the carbon had been removed from solution, the greater the ratio of C to Cl_2, the greater was the removal of chlorine. With a C : Cl_2 ratio of 3.9 : 1, all of the chlorine disappeared upon standing overnight. Experiment (2) showed, after a half-hour contact, a reduction in available chlorine from 354 p.p.m. to 35 p.p.m. an increase in chlorides from 179 p.p.m. to 290 p.p.m., and a drop in pH from 5.3 to below 4.0.

Although no quantitative relation could be established, it is evident that activated carbon has a deleterious effect on the bactericidal action of chlorine. This effect is due to the removal of chlorine from solution by the carbon. The ability of activated carbon to remove chlorine from solution has been demonstrated in water works practice by a number of investigators.

Experiment (2) gives some insight into the mechanism of the chlorine removal. A number of investigators, including Bohart and Adams (4) and Gibbs (9) have advanced the following equation:

$$2Cl_2 + 2H_2O + C = 4HCl + CO_2$$

Behrman and Gustafson (2) state that Baylis, in unpublished work, found a time lag in the appearance of chloride, probably due to adsorption and concentration before the reaction took place.

Whether or not this is actually the reaction, it is certain that HCl is formed, as evidenced by the drop in pH accompanied by an increase in chloride content. If chlorine and activated carbon are both to be

TABLE IV.—*Effect of Activated Carbon on Bactericidal Action of Chlorine*

(1) 20° C. Total Counts

P.p.m.	Cl_2 Added Per Cent Demand Satisfied	P.p.m. Activated Carbon	20° C. Count Thousand Organisms per Cc.	Per Cent Kill
Trial 1 (Cl_2 demand = 2.85 p.p.m.)				
0	0	0	2630	
1.42	50	0	70.4	97.32
1.42	50	5.5	TM*	—
2.85	100	0	4.1	99.84
2.85	100	11	TM*	—
100% Cl_2 removal from stock solution by the carbon overnight Ratio of C : Cl_2 = 3.9 : 1				
Trial 2 (Cl_2 demand = 10.23 p.p.m.)				
0	0	0	2310	
5.12	50	0	17.38	99.25
5.12	50	5.5	2380	0
10.23	100	0	2.73	99.88
10.23	100	11	331	85.67
95% Cl_2 removal from stock solution by the carbon overnight Ratio of C : Cl_2 = 1.1 : 1				
Trial 3 (Cl_2 demand = 10.8 p.p.m.)				
0	0	0	1410	
5.4	50	0	25.8	98.17
5.4	50	5	186	86.81
10.8	100	0	1	99.93
10.8	100	10	5	99.65
69% Cl_2 removal from stock solution by the carbon overnight Ratio of C : Cl_2 = 0.9 : 1				

(2) Effect of Activated Carbon on Cl_2 Solution

350 p.p.m. carbon, 1/2 hour contact

	Without Carbon	With Carbon
Available Cl_2	354 p.p.m.	35 p.p.m.
Chlorides	179 p.p.m.	290 p.p.m.
pH	5.3	2.8–4.0

TM* = Too many organisms to count.

used in the treatment of water or sewage, the two substances should be added separately—the chlorine well in advance of the carbon.

Activated Carbon in Activated Sludge Treatment

In an effort to determine the effect of activated carbon on the clarification and purification of activated sludge effluent and the settleability of the sludge formed, a series of experiments were conducted with different periods of aeration. Samples of return activated sludge containing about 4,000 p.p.m. suspended solids were mixed with raw sewage in proportion of 1 : 1. Each sample was divided into five portions and two used as duplicate controls; 10 p.p.m. powdered activated carbon was added to a third sample of sewage before mixing with the sludge; 20 p.p.m. of carbon to a fourth; and 40 p.p.m. to the fifth. The mixtures were then aerated in cylinders. At the end of the aeration period the sludge was settled and the supernatant liquor drawn off. Fresh sewage was added to the sludge to a total volume of 900 cc. with carbon added as in the first run. A series of twenty-nine such runs were made. The suspended solids content of the mixtures was kept between 1500 and 2000 p.p.m. The aeration time of the runs varied from one to seventeen hours.

At the end of each run, determinations were made of the volume of sludge settled in a half hour, and of the turbidity and oxygen-consumed values of the supernatant liquor. The average condensed results are shown in Table V.

Table V.—*Average Oxygen Consumed and Turbidity of Supernatant and Settleability of Activated Sludge*

	Activated Carbon Added in P.p.m.					
	0	0	10	20	40	Ave. Hrs. Aeration
Oxygen Consumed, P.p.m.	39	39	40	37	39	2
Turbidity, P.p.m.	42	41	42	44	47	3.5
Sludge Settled, C.c./L.	178	178	168	178	194	3.5
Sludge Settled, C.c./L.	150	155	151	151	157	13.5

No effect was produced by the activated carbon on the turbidity or the oxygen-consumed value of the effluent. Ten p.p.m. of carbon produced persistently a slightly more compact sludge than was obtained without carbon, but this difference amounted to only 6 per cent, which was lost with the larger doses of carbon. The difference in compacting of the sludge obtained with 10 p.p.m. activated carbon was of such small magnitude that the results are of no practical value even if the difference was actually due to the carbon, and not to experimental error.

Effect of Activated Carbon on Sludge Digestion

The fact that activated carbon changes the acidity of sewage and sludge and has the faculty to absorb a variety of substances may conceivably be made use of in cases where sludge digestion tanks are in a poor condition, where new plants are started without proper quantities of seed material and where toxic trade waste substances are present. The results obtained with poorly digested sludge and with the re-use of the sludge secured from these mixtures for seed are presented as of most interest.

Method.—(1) Batches of poorly digested sludge and fresh solids were collected at the Plainfield, N. J. treatment plant and divided into three portions. The fresh solids were seeded with the sludge on a 2 : 1 volatile matter basis. The ripe sludge was of poor quality, not being thoroughly digested and apparently containing toxic substances which retard digestion. The total volume of each fresh solids-ripe sludge mixture was 1.5 liters. One sample was used as a control; 10 grams of powdered activated carbon was added to a second, and 20 grams of carbon was added to the third. The samples were incubated at 25° C. and gas was collected.

Daily gas measurements were made, and the pH, total solids, and ash content of the mixtures were determined at intervals during the periods of digestion

When the digestion of each sample was completed, the drainability of the sample was determined by filtering a 100-c.c. portion through a Buchner funnel under a 21-inch vacuum and measuring the amount of liquid filtered after 2 hours.

(2) When the two mixtures containing 10 and 20 grams, respectively, of carbon were thoroughly digested, they were used as seed for the digestion of fresh solids collected at the Freehold, N. J., treatment plant. Additional carbon was added to each of the newly prepared mixtures, so that the total amount of carbon present in each mixture was 10 and 20 grams per 1.5 liters, respectively. The mixtures were incubated at 25° C. and determinations and measurements were made as in Experiment 1.

Results.—(1) The condensed results in Table VI show that activated carbon materially accelerated the digestion of the fresh solids. Ten grams of carbon per 1.5 liters reduced the digestion time by one-half, or from 127 days to 69; 20 grams reduced the time by two-thirds, to 42 days. An acceleration was also evident in the time required for the daily gas production to reach a peak. One-third the time was required with the 10 grams of carbon, and one-sixth the time with 20 grams.

The cumulative results on gas production per gram of volatile matter added is shown in Fig. 5. Total gas production was stimulated by the carbon, but with 20 grams of carbon, less gas was produced than with 10 grams.

TABLE VI.—*Effect of Activated Carbon on Digestion of Improperly Seeded Sludge*

	Control		10 Gms. Carbon per 1.5 Liters		20 Gms. Carbon per 1.5 Liters	
	At Start	At End	At Start	At End	At Start	At End
Digestion Time (Days)	127		69		42	
Time to Reach Gas Peak (Days)	110–115		35		18	
pH	5.7*	7.3	5.9*	7.6	6.3*	7.6
% Total Solids	6.53	3.98	6.63	4.21	6.49	3.89
% Ash	29.7	43.8	30.4	44.6	31.8	52.8
% Dry Volatile Matter	4.59	2.24	4.62	2.33	4.42	1.182
% V.M. Destroyed	51.3		49.6		58.8	
C.c. Gas/Gm. V.M. Added	745		1044		870	
C.c. Gas/Gm. V.M. Destroyed	1017		2060		1480	
Drainability **	47		60		79	

* 4 days after actual start.

** C.c. filtrate collected from 100 c.c. sludge in 2 hours upon filtration through Buchner funnel under 21 inch vacuum.

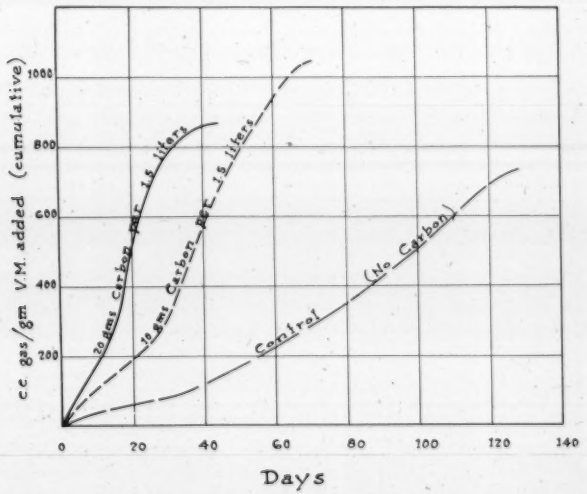

FIG. 5.—Effect of activated carbon on gas production.

With 10 grams of carbon, there was no effect on the percentage volatile matter reduction as compared with the untreated material; with 20 grams the volatile matter reduction was increased by 16 per cent.

The pH of the mixture containing carbon did not drop as low during the initial period of digestion as did the pH of the control; also the pH values of the carbon-containing mixtures rose more rapidly as the digestion progressed.

The activated carbon greatly improved the drainability of the digested sludge, greater improvement being obtained with the larger portion of carbon.

(2) Condensed results on the reuse of activated carbon are given in Table VII. In this case, where some of the carbon was already present

TABLE VII.—*Effect of Reuse of Activated Carbon in Sludge Digestion*

	10 Gms. Carbon per 1.5 Liters		20 Gms. Carbon per 1.5 Liters	
	At Start	At End	At Start	At End
Digestion Time (Days)	36		31	
Time to Reach Gas Peak (Days)	22		20	
pH	6.7	7.6	6.9	7.7
% Total Solids	3.77	3.06	3.84	2.95
% Ash	35.9	44.6	38.8	49.1
% Dry Volatile Matter	2.42	1.70	2.35	1.50
% V.M. Destroyed	30.0		36.1	
C.c. Gas/Gm. V.M. Added	642		553	
C.c. Gas/Gm. V.M. Destroyed	1565		1188	
Drainability *	81		80	

* C.c. filtrate collected from 100 c.c. sludge in 2 hours upon filtration, through Buchner funnel under 21-inch vacuum.

in the seed material and had been used in a previous digestion, the differences in effects produced by 10 and 20 grams of carbon were not as pronounced as in Experiment 1, where all of the carbon was used for the first time.

There was a difference of only two days in the time required to reach a peak in gasification, and of five days in the time required for thorough digestion. The amount of gas produced was not as great as in Experiment 1, but was within the limits of average gas production for digesting sludge. Here again the gas produced with 20 grams of carbon was less than with 10 grams. The volatile matter reduction was practically the same in both mixtures.

Discussion.—The 10- and 20-gram portions of carbon represent dosages of 20 to 33 and 40 to 67 p.p.m., respectively, in the raw sewage, based on 3 to 5 c.c. of settleable solids per liter in an average sewage, and on the assumption that all of the carbon added to the sewage settles with the solids. The latter assumption has been borne out by observations made during field experiments conducted at the East Rochester, N. Y. and the Princeton, N. J. treatment plants.

The gas production in Experiment 1 was considerably above the average from all three mixtures, due to the fact that the seed material had not been thoroughly digested before use. The partly digested material contributed to the total gas produced. However, the acceleration of digestion and the increase in the gas production obtained with the activated carbon are very pronounced and leave no doubt as to the effect produced by the carbon.

The decrease in gas production with 20 grams of carbon as compared with the gas production with 10 grams may be due to adsorption of some of the gas by the additional carbon. That is, the gas may have been formed, but held by the carbon. This possibility is strengthened by the fact that the volatile matter reduction was greater with the larger portion of carbon.

These results, as well as the reaction control evidenced by the higher pH values throughout the digestion with carbon, and the improved drainability, indicate that activated carbon would be of considerable value when digestion tanks are operating poorly, when the digestion activities are upset, and possibly when trade wastes are present which produce acid conditions. At present it is standard practice to control poorly operating tanks by the addition of very large quantities of lime. The dosages of carbon used in this experiment were quite large, but were arbitrarily chosen.

The results of Experiment 2 indicate that the activated carbon had rendered innocuous in the previous run any toxic material; and further that the carbon is not as effective when the digestion activities are progressing properly as when improper conditions prevail.

Drainability of Sludge.—The drainability of sludge digested in the presence of activated carbon improved materially. Experiments were also made on the addition of carbon to digested sludge, activated sludge and digested sludge treated with chemicals for dewatering. When treating properly digested sludge with activated carbon, varying in quantities from 0 to 1000 mgr. per 200 c.c. sludge and filtering under a 21 in. vacuum, no increase in removal of water was obtained. Filtering sludge, to which chemicals were added for dewatering, with activated carbon caused a slight increase in the amount of water drained off. There is apparently a minimum quantity of activated carbon which

helps dewatering. Increasing the quantity of carbon speeds up filtration. In general the results with iron-salt treated sludge were much the same as with properly digested sludge.

Addition of carbon to activated sludge increased the rate of filtration materially. A series of filtration curves indicate that the quantity of water removed was practically constant, but that the filtration rate was doubled by using 100 mgr. carbon per 100 c.c. sludge containing 6000 p.p.m. suspended solids. With larger quantities of carbon the filtration rate was still further increased, so that with 1000 p.p.m. carbon the same amount of water was produced in one-sixth of the time required for the sludge without carbon.

Use of Activated Carbon with Trickling Filter Effluents

Method.—(1) Ten to 50 p.p.m. portions of powdered activated carbon were added to 500 c.c. samples of trickling filter effluent, which were allowed to stand for 15 minutes, filtered to remove the carbon; and oxygen consumed values (30-minute, hot) of the filtrates were determined. Control samples were also filtered.

(2) Five and 12 p.p.m. portions of powdered activated carbon were added to 500 c.c. samples of trickling filter effluent, allowed to stand for 15 minutes, and the 5-day B.O.D. determined of each of these filtrates and of the filtrate from an untreated sample.

Results.—The carbon did not effect any reduction in the oxygen consumed value of the effluent, which was approximately 62 p.p.m. in all samples.

An untreated sample of effluent, filtered through paper, had a B.O.D. of 11.3 p.p.m. With 5 p.p.m. carbon the B.O.D. was 9.7 p.p.m.; with 12 p.p.m. carbon 8.6.

With any type of oxidation device used in sewage treatment, it is extremely difficult to remove the remaining organic material as indicated by the B.O.D. or oxygen-consumed value. This is due to (1) the small quantity remaining, and (2) to the state of oxidation or rather the stability of the organic matter which has been oxidized under influence of biological action.

Odor Control

The removal of odor by activated carbon is well known in water treatment. The question of odor reduction as well as prevention of odor production in sewage is of considerable interest. Some experiments were performed to determine the quantity of H_2S which could be removed from stale sewage, and whether addition of carbon would prevent odor production when left in contact with sewage for a considerable time.

Method.—(1) Raw screened sewage was stored in a stoppered bottle

for 14 days, until it contained 4.8 p.p.m. sulphides (as H_2S) and had a marked H_2S odor. To aliquot portions, 0, 15, 50, and 100 p.p.m. powdered activated carbon was added and left in contact for 30 minutes. The odor thresholds of the samples were then determined by diluting with distilled water and the results expressed in terms of pO.

(2) Sewage containing 4.0 p.p.m. sulphides was filtered at the rate of 1.5 liters per minute through a bed of 4 to 10 mesh granular activated carbon $1\frac{1}{2}$ inches deep and $2\frac{1}{2}$ inches in diameter (approximately 10 grams of carbon). The sulphide content of the filtrate was determined by acidifying with HCl and aerating for one hour with CO_2; passing the gases through 2 per cent zinc acetate solution; adding N/50 iodine to the zinc acetate, which was then acidified and transferred to a beaker and the excess iodine titrated with N/50 sodium thiosulphate.

(3) Four aliquot portions of sewage were stored in one-gallon bottles and tightly stoppered. Before incubation 0, 10, 250 and 1000 p.p.m. activated carbon were added and after 5-days incubation the sulphide content determined.

Results.—(1) The untreated sewage had a pO value of 10; 15 p.p.m. carbon did not reduce the pO after 30 minutes contact; 50 p.p.m. carbon reduced the pO value to 9; and 100 p.p.m. reduced the pO to 6.

(2) The granular carbon filter removed 2.2 p.p.m. of the 4.0 p.p.m. of sulphides in the sewage; no H_2S odor was noted in the filtrate.

(3) The untreated sewage, after standing for five days, contained 3.0 p.p.m. total sulphides (calculated as H_2S); the sewage treated with 10 p.p.m. carbon contained 10.0 p.p.m. sulphides; the sewage with 250 p.p.m. of carbon contained 11.4 p.p.m. sulphides; and the sewage with 1000 p.p.m. carbon contained 9.5 p.p.m. sulphides.

It is evident that the carbon effected a slight reduction in the odor of the very stale sewage. This, however, does not necessarily mean that activated carbon is incapable of reducing odors in sewage. It is a well known fact that hydrogen sulphide is generally the chief source of odor in a sewerage system or a sewage treatment plant. As seen from the results in experiment (2) the granular carbon filter removed 2.2 p.p.m. of the total sulphides, and apparently removed all the free H_2S. Probably powdered carbon under proper conditions would produce similar results.

Experiment (3) was performed to determine whether incubation with activated carbon would retard the production of hydrogen sulphide in sewage allowed to become very septic. The results show that the carbon accelerated the H_2S formation. It would appear that the use of activated carbon for retardation of H_2S production in sewage which is stored for a considerable time has no practical value. However, it is highly interesting from a theoretical standpoint. Although it is merely conjecture

to hazard any explanation of this phenomenon of accelerated H_2S production, it is possible that the carbon may concentrate, at its surface, the sulphates or sulphur-bearing proteins in the sewage, rendering them more available to the sulphate-reducing and protein-splitting organisms; or the carbon particles may act as nuclei to which the organisms may attach themselves and around which they may grow. The fact that decomposition of sewage sludge is accelerated by the addition of activated carbon may be, in part, explained on the same basis. If this is correct, the results obtained in this test are in the nature of confirmatory evidence.

Field Experiments

Princeton, New Jersey

Experiments were conducted at the Princeton, N. J., sewage treatment plant over a period of 23 weeks (from January 30 to July 10, 1935) to study various phases of the use of activated carbon in plant operation. The principal objects of the investigations were to determine, if possible, the effect of activated carbon on sludge digestion, suspended solids and B.O.D. reduction in the primary tanks, and odor production.

The Princeton plant treats on an average 1.3 m.g.d. and consists essentially of a coarse bar screen, primary settling tanks, eight square digestion tanks, trickling filters, final settling tanks and glass-covered sludge drying beds. The bar screen is located at a pump house about 1/4 mile ahead of the plant.

The hopper-bottomed digestion tanks are each 26 ft. deep and 20 ft. square. The tanks are unheated, located above ground level, insulated by earthen banks and have fixed concrete roofs fitted with metal covers. During the winter months the temperature of the sludge was at times as low as 43° F.

The activated carbon was added to the sewage on Wednesday, Thursday and Friday of each week by means of a dry-feed machine located at the pump house. This method of application insured thorough mixing of the carbon with the sewage by the time it reached the settling tanks.

At the start of the experiments the daily dosage of activated carbon was 35 lb., and after the first week the dosage was increased to 70 lb., or approximately 53 lb. per million gallons based upon the average sewage flow. Since the total sewage flow received carbon it was necessary to treat the sewage a part of the week in order to obtain comparative results. Each week about 420 cu. ft. of the solids settled from the sewage during the first part of the week (without carbon) were put into a digestion tank, which was used for control; an equal portion of the solids settled during the latter half of the week (containing carbon) was pumped into another

tank for comparison. The remainder of the settled solids was diverted in each case to the other six digesters.

Observation and occasional tests did not disclose any carbon in the effluent from the settling tank so it may be assumed that practically all of the carbon settled with the sludge.

Digestion.—The purpose of the digestion experiments was primarily to study the effect of comparatively small quantities of activated carbon upon volatile matter reduction, clarification of supernatant liquor, sludge concentration, scum blanket formation, pH of sludge, drainability of digested sludge, and changes in composition of gas (CO_2 content) produced.

Before actual experimentation was begun samples from the top to bottom of the eight digestion tanks were taken and analyzed. The two tanks chosen for future analyses and observations were the two most nearly alike in solids content, pH values and distribution of solids in the tanks. The tank receiving activated carbon sludge had approximately the same solids content, but the scum blanket was materially thicker.

During the period of investigation, samples of the sludge in these two tanks were taken weekly at a depth of one foot from the surface, and at intervals in depth of 3 feet, down to a level of 19 feet from the surface. Analyses consisted of total solids, ash and pH. When the tanks were filled after six weeks operation, sludge was drawn in equal amounts to provide for incoming sludge and to maintain conditions in the tanks for comparison.

Gas for analyses was collected from the digesting sludge in domes made of inverted metal cans, fitted with rubber tubing. The cans were left in portions of the tanks not disturbed by sampling. On the days when samples of sludge were collected, the tubing was closed in the morning so that an appreciable amount of gas would collect by afternoon, when the CO_2 content of the gas was determined.

The solids concentrations at different depths in the tanks at the beginning and end of the experiment are graphically shown in Fig. 6. The scum layer in the tank which had received sludge with carbon had been reduced by more than half and the concentration reduced to about one-third. At the same time the zone of supernatant liquor had increased greatly and considerably more than in the tank without carbon. Averaged results for four-weekly intervals of the sludge concentration are shown in Table VIII. From these results it is evident that solids reduction in the tank with carbon was greater and more rapid than in the tank without carbon. In 20 weeks the reduction of dry solids in the control tank amounted to 26.2 per cent of the original solids present, while the solids reduction in the tank with carbon amounted to 57.6 per cent. The percentage reductions are caused in part by the with-

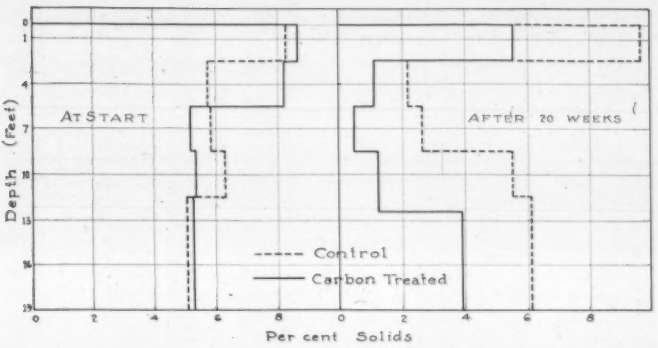

FIG. 6.—Solids concentration at different depths in the tanks at beginning and after 20 weeks.

TABLE VIII.—*Total Solids at Different Depths of Tanks*
(Results in Percentage of Four-weekly Averages)

	Control Tank					Tank Receiving Nuchar				
Depth in Ft.	1	4	7	10	13–19	1	4	7	10	13–19
Weeks										
0	8.31	5.80	5.88	6.36	5.12	8.72	8.26	5.20	5.36	5.30
1– 4	9.37	3.94	4.38	4.52	5.21	9.60	3.82	4.06	4.95	5.87
5– 8	12.21	1.24	2.65	4.26	5.15	9.34	1.00	1.51	3.07	4.92
9–12	14.50	1.07	3.72	4.56	5.34	10.06	0.90	0.53	2.79	4.24
13–16	11.64	1.53	—	4.11	4.87	10.54	0.80	—	1.11	4.31
17–20	8.76	1.27	1.74	4.52	5.12	5.63	1.13	0.50	1.22	3.95
21–23	5.76	1.18	—	4.69	4.90	5.90	1.00	—	0.60	3.62

drawal of sludge and in part by the digestion of the solids. During most of the experimental period little actual digestion took place in the tank without carbon on account of the low temperature, so that most of the reduction recorded was caused by withdrawal. Approximately similar quantities of sewage were withdrawn from the tank with carbon, leaving a percentage difference of 31.4. This figure is probably too high as indicated by the laboratory experiments, there solids reduction and gas production after 42 days, when the best was digested, were as follows:

Carbon, grams/1.5 l.	0	10	20
Gas, cc/gram V.M.	139	621	870
Solids, red. %	16.2	32.4	49.5

Similar reductions in volatile matter are found when the results on the two tanks are compared. However, the differences in ash content were much smaller. The average results for the two tanks at beginning and end are given in Table IX.

TABLE IX.—*Average Solids, Volatile Matter and Ash of Treated and Untreated Sludge at Beginning and End (Entire Tank)*

	Control	Carbon
Solids:		
Beginning	5.97	6.20
After 20 Weeks	4.36	2.63
Red., Per Cent	26.2	57.6
Volatile Matter:		
Beginning	3.76	4.01 *
After 20 Weeks	2.94	1.75 *
Red., Per Cent	21.8	56.4 *
Ash:		
Beginning	35.1	34.5
After 20 Weeks	35.2	37.5
Increase, Per Cent	0.3	8.0

* Correction made for carbon present (3.2 per cent of dry solids).

The most noticeable difference in distribution and concentration of the solids was found to be in the upper portion of the tank receiving carbon. This layer, where the supernatant liquor was located, increased gradually in depth. The progressive decrease in solids concentration at the 10-ft. level is shown in Figure 7. At this level the solids concentration in the control tank decreased from 6.37 to 4.69 per cent, or a percentage decrease of 26.3, while the solids concentration in the tank receiving carbon-treated sludge was reduced from 5.36 to 0.60 per cent, or a percentage decrease of 86.9.

The pH values of the sludge in the two tanks varied from 6.7 to 7.2 in the scum layers and from 7.1 to 7.4 in the sludge located at all other levels. The carbon had no appreciable effect on the pH values of the materials.

The percentage of CO_2 in the gas produced from the untreated material varied from 15.0 to 19.5, with an average of 16.9, while the CO_2 content of the gas collected from the treated sludge varied from 11.5 to 19.0, with an average of 15.2 per cent. Although no gas measurements were made, visual observations indicated more rapid gasification of the treated sludge.

The analytical data in Table VIII do not show appreciable differences between the two tanks at a depth of one foot, where the scum blankets were located. There was, however, a decided difference in the appearance of the two scum masses. The scum in the tank which received sludge with carbon soon acquired a uniform nonrubbery consistency, and the gas

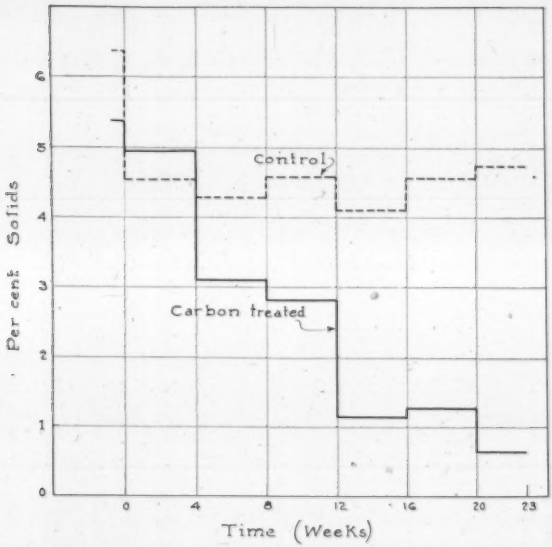

FIG. 7.—Progressive decrease of solids concentration at 10 foot level (supernatant liquor zone).

could be noted escaping continuously and evenly distributed throughout the surface, while the scum in the control tank remained rubbery and lumpy, allowing the gas to escape through only a few unevenly distributed craters.

No accurate analytical data were obtained on the drying of treated and untreated sludge, but the operator of the plant asserts that the carbon-treated sludge dried on sand beds more rapidly than the untreated sludge. This is in accordance with laboratory findings, but further investigations will be required to establish this observation definitely.

It is evident from the results reported that the activated carbon added in quantities of about 6.5 p.p.m. to the raw sewage aided considerably in the separation of solids and supernatant liquid. The mass of floating solids in the upper zone of the tank decreased and the zone of supernatant liquor was deeper, thereby increasing the capacity of the tank and allowing the handling of supernatant liquor with less difficulty.

The reduction in the overall average of solids in the entire tank is of

considerable interest. The increase in the percentage reduction in the carbon-treated sludge appears to be due to decomposition, but the percentage ash increase was not in proportion to the percentage volatile matter reduction. Since no gas collection facilities are available at the plant, only visual observations could be made. The CO_2 content of the gas produced by the sludge receiving carbon was as a rule somewhat lower than in the gas from the untreated tank. All indications point in the direction of greater organic matter reduction, due primarily to liquefaction and in secondarily to gasification. This is in line with known facts that at low temperatures liquefaction is stimulated. The result of the destruction or liquefaction of the solids is facilitation of operation and less sludge to be handled. At higher temperatures gas production would probably increase with a gas of a slightly lower CO_2 content or higher heat value.

The time required for the improvement was rather long. The work was conducted during the period of the year when the mass of the sludge remained at low temperature, with very little opportunity for digestion during a considerable portion of the time. The quantity of activated carbon added during the entire period amounted to only 3.2 per cent of the total dry solids. For rapid improvement it would appear that a larger quantity of carbon added at the beginning, followed by small dosages, should produce much more rapid results under similar conditions.

Suspended Solids Removal and B.O.D. Reduction.—For the determination of the effect of activated carbon on the suspended solids removal and B.O.D. reduction of the sewage passing through the primary settling tank, four-hour composite samples were taken of the influent and effluent. Samples were taken on days when activated carbon was added and on days when no applications were made. The results obtained indicate that the activated carbon did not have any effect on the suspended solids and B.O.D. reductions. This corroborates results obtained in the laboratory and discussed previously.

Odor Control.—Due to seasonal conditions during most of the time the experiments were in progress, odor production at the plant was very slight or absent. As soon as odors were found to be present four-hour composite samples were collected of the influent and effluent. The quantities of H_2S were never large. Some results on composite samples of raw sewage and effluent from the primary tank are shown in table on page 876.

The results obtained were not sufficient to draw conclusions, but they show that the carbon may be of considerable value for odor reduction at sewage plants.

	P.p.m. H_2S		Per Cent Reduction
	Influent	Effluent	
Untreated	0.9	0.5	44
Carbon Treated	0.6	0.1	83
Untreated	1.7	1.2	30
Carbon Treated	1.8	0.4	78
Untreated	1.2	0.7	42
Carbon Treated	1.0	0.2	80

East Rochester, New York

After laboratory experiments had been in progress for a period of about 9 months, the operator at the East Rochester, N. Y. plant began the first plant-scale experiments with activated carbon (Nuchar). During November, 1934, the junior author made a survey of the plant and took samples of the sewage and sludge in the digester. The East Rochester plant consists essentially of a coarse screen, detritor, revolving fine screen, two-story circular settling and digestion tank, trickling filter and sludge drying beds. The sludge compartment of the tank is heated by passing supernatant liquor through a gas boiler using sludge gas as fuel. A large portion of the sludge compartment is above ground and not insulated, making temperature control difficult. The plant, designed for 1.2 m.g.d., was treating 200,000 gal. daily during the period of experimentation.

Activated carbon was added in dosages of 1 or 2 pounds at intervals throughout the day by means of a perforated pail suspended in the flow channel between the fine screen and settling tank. The flow of carbon lasted about 5 minutes each time, with the result that a good deal of the carbon floated on the surface in the scum chamber for about an hour, after which time it had all settled. No carbon was visible in the effluent. The dosage applied was 25 lb. per m.g. from Oct. 23 to Nov. 24, after which it was increased to 50 lb. per m.g. The results given below were obtained during the period of low carbon application.

In addition to measuring daily gas production and temperature of the sludge, total solids, ash and pH values were determined at one-foot intervals through the depth of the sludge in the tank. The various depths were considered in an attempt to determine whether there was any compacting occurring due to the Nuchar. Suspended solids, B.O.D. and pH of the screened sewage, tank effluent and final effluent, and suspended solids and pH of the supernatant liquor were determined. Sludge samples were obtained with a pitcher pump to which a length of hose was attached.

Observation and Results.—Visual observations of the settling chamber showed very little scum on the surface of the tank; what little was present appeared to be grease. Only one inch of scum appeared at the top of the supernatant liquor. There was a distinct line of clearance between the sludge and supernatant liquor.

The average pH values of the sludge in the tank varied from 7.2 to 7.3 from top to bottom, and the supernatant liquor one foot above the sludge 6.9. The average sludge densities and ash contents were as follows:

Depth of Sludge Ft.	Total Solids Per Cent	Ash Per Cent
1	9.73	62.3
2	10.94	61.1
3	10.50	62.6
4	12.03	63.3
5	12.26	61.4

The supernatant liquid was very clear, containing 162 p.p m. suspended solids and a B.O.D. of 335 p.p.m.

Gas production and temperature of the sludge were as follows:

Without Carbon (Average previous 22 days)	With Carbon (Average 36 days)
Gas 1,345 cu. ft./day	2,667 cu. ft./day
Temperature 60° F.	62° F.
Temperature Sewage 59.2° F.	63.0° F.

Analyses of 14 samples of gas produced since the addition of carbon showed an average CO_2 content of 30.1 per cent, which according to Mr. Wm. A. Ryan, Consulting Engineer, was about the same as obtained prior to the addition of carbon.

The average removal of suspended solids in the settling tank amounted to 67.8 per cent, while the average removal for the previous 18 months was 67.25 per cent. The average B.O.D. reduction during the previous 24 months amounted to only 10.8 per cent, while the few samples taken during the period of experimentation showed somewhat higher results.

The most interesting results of these experiments were in connection with the gas production. Two days after carbon additions were begun the gas production increased greatly and was still at the high level when the survey was made. On the basis of the sewage analyses available the amount of gas produced would be about 10.6 cu. ft. per lb. dry solids, while the quantity during the previous 22 days would correspond to about 5.4 cu. ft. per lb. dry solids.

The sludge concentration in the tank was rather high, with a gradual increase towards the bottom, and sludge samples showed high ash con-

tents. The analyses of the samples collected throughout the depth of the tank on the several occasions do not show any relationship between the carbon added and compacting of the sludge.

The addition of the carbon did not appear to affect the suspended solids settled in the tank, results which correspond to those found at the Princeton plant and in the laboratory. The composite samples of the supernatant liquor showed remarkably good separation of the solids from the liquid. Since no corresponding results are available for the plant prior to the addition of carbon, it cannot be said that the clarification of the liquor was enhanced by the carbon.

General Discussion

The experimental work reported on the use of activated carbon in sewage was essentially in the nature of a survey but the results obtained in several instances, both in the laboratory and field, are of sufficient detail and duration to allow rather definite conclusions. In several instances the results indicate what phases of the work will merit further investigations, with possibilities of practical application.

Perhaps the most interesting results of practical value were obtained in connection with sludge digestion. The activated carbon materially accelerated the digestion of poorly digesting material, increased gas production, produced a greater volatile matter reduction, affected the pH values of the material and produced a ripe sludge of better dewatering quality. In addition the carbon apparently removed toxic substances which were present in the sludge. The field results checked remarkably well with those obtained in the laboratory. The carbon did not cause a greater gas production per pound of volatile matter destroyed, but the rate of destruction of volatile matter was greater than without carbon. The result was a greater quantity of gas in a given time. The time required to destroy a given quantity of volatile matter was also shorter, so that the gas produced in a given time from the same quantity of volatile matter added was considerably greater with carbon than without carbon. Properly seeded material, digesting at more nearly optimum temperature, was very little affected by the carbon. The after-effect of the carbon on digestion was but slight. This is to be expected, when the action of the carbon is considered in relation to its adsorptive and alkaline qualities. It appears, therefore, that carbon is of greatest interest where tanks are overloaded, operating poorly and the temperature is low. The effect of the carbon on the changes of pH values in poorly digesting mixtures can probably be correlated with the faculty of the carbon to adsorb CO_2 and volatile acids. The laboratory studies show that organic acids, such as butyric, are adsorbed readily. The adsorption varies with the type of carbon. For instance, a number of

commercial activated carbons varied as follows in regard to adsorption of butyric acid, using 500 mgrs. carbon of each:

Carbon	Mgr. Butyric Acid Adsorbed
A	122
B	103
C	100
D	94
E	75
F	70
G (not activated)	37

Since the adsorption of CO_2 and volatile acids is undoubtedly a factor in the control of reaction, and probably the adsorbed volatile acids are destroyed more rapidly by the bacteria, it is of practical interest to use those carbons which have the greatest adsorption power. Part of the adsorbed CO_2 is very likely neutralized by some of the carbons which are alkaline in nature. These alkaline carbons perform in some respects a function similar to lime, when added for reaction control. The removal of organic acidic substances from the liquid and their more rapid destruction, either when adsorbed or after reaction with the alkali of the carbon, would materially aid digestion. The resultant increase in bacterial action would further stimulate decomposition and cause possibly greater volatile matter destruction, thus producing a sludge more easily dewatered.

The results obtained do not show any appreciably greater B.O.D. reduction of the raw sewage when activated carbon was added. This is probably due to the fact that the carbon has a limited power of adsorption so that when highly oxidized effluents are treated with carbon, practically no further B.O.D. removal takes place, but when incompletely oxidized effluents are treated or effluents such as those from a chemical precipitation process, containing considerable B.O.D. caused by soluble and semi-soluble substances such as organic acids, certain fatty materials and soaps, which are not removed by coagulation, the activated carbon causes a reduction in B.O.D.

The faculty of activated carbon to adsorb fatty acids is of interest in connection with scum formation on settling and digestion tanks. These fatty acids are a factor in scum production on account of their spreading quality and effect on charges in surface tension. The removal of the fatty acids from their sphere of influence, either temporarily or permanently, would allow more solids to settle, or would prevent their flotation. The result would be cleaner surfaces of tanks, and especially the final tanks of plants where a relatively large percentage suspended solids reduction is obtained, but where the effluent is not highly oxidized, or where the quantities of fatty acids are proportionately large.

Theoretically the addition of activated carbon should also increase the removal of suspended solids in settling tanks, but the relatively long time employed in settling, allowing practically all settleable solids to be removed, would not show this by analytical results. Only in cases of exceedingly short detention periods, or where large quantities of grease and soap are present, would the carbon be effective. In order to be effective in such cases the quantities of carbon to be used would probably be out of proportion to the results obtained, so that such a procedure may not be economical.

The laboratory and few plant results available indicate that activated carbon would accomplish odor reduction. On the other hand odor production would not be retarded by the carbon. This means, therefore, that addition of activated carbon to sewers would prevent release of a part of the odor-producing substances, but would be only of a temporary nature. Addition of carbon to the influent for purposes of scum removal would incidentally be effective in odor reduction.

As far as could be determined by laboratory experimentation, activated carbon did not have any effect upon the purification power of activated sludge, and the effect on the compacting of activated sludge was so slight that the differences were within the limits of experimental error.

Summary and Conclusions

Laboratory and plant experiments were made in the nature of a survey to determine the possible use of activated carbon in sewage treatment. From the results obtained a number of general conclusions may be drawn:

1. The activated carbon raised the pH and reduced the total acidity fo sewage, due to the adsorption of carbon dioxide and volatile fatty acids.

2. The carbon did not aid in flocculation of suspended solids in sewage, nor in the flocculation of solids with ferric chloride. It reduced the efficiency of chlorine as a sterilizing agent.

3. No increase in purification by activated sludge treatment was caused by the addition of carbon.

4. The carbon materially accelerated the digestion of sludge of poor quality, sludge containing toxic materials, improperly seeded sludge, and sludge digesting at low temperature. Gas production was increased, volatile matter reduction was greater, the pH value was maintained at a higher level, carbon dioxide in the gas was lower, and the rate of dewatering of digested sludge was increased in proportion to the amount of activated carbon added.

5. The B.O.D. of raw sewage and highly oxidized effluents was not reduced by activated carbon, but the B.O.D. of incompletely oxidized effluent and effluent from chemical treated sewage was reduced.

6. Scum formation on settling tanks was materially reduced by the activated carbon.

7. Odor reduction was obtained, but storage of sewage with activated carbon accelerated H_2S production.

8. A better separation of sludge and liquor was attained in digestion tanks, with a wider supernatant liquor zone and less solids in the liquor.

9. Not all activated carbons used are equally effective in reduction of acidity and volatile fatty acids.

Acknowledgment

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Plant Operation

GAS COLLECTION AND SLUDGE HEATING

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The practice of collecting the gases generated by the digestion of sewage sludge and using them for temperature control of the digesting sludge has come into such widespread use in recent years that this procedure is the rule rather than the exception at the newer sewage treatment plants where separate sludge digestion is employed. This is particularly true in those sections of the country where cold winters are prevalent, but digestion tanks are also being heated in many of the warmer parts of the country.

So much has been written concerning the benefits which may be derived from maintaining high temperatures in sludge digestion tanks that detailed consideration of this point will not be undertaken. The principal advantage lies in the generally accepted fact that digestion of sludge at or near a temperature of 82° F. makes possible a materially shorter digestion time and consequently smaller digestion tanks than is the case where no heat is applied. In correlating available data of various investigators concerning the influence of temperature upon time of digestion, Fair and Moore [1] have indicated that the time required for digestion of plain-sedimentation sludge at a temperature of 50° F. may be more than three times as great as at 82° F.

This paper includes general information and operating experiences which it is hoped will interest non-technical operators, as well as data of primary interest to designing engineers. Since there are a limited number of sewage treatment plants in Pennsylvania where gas is collected and sludge is heated, there are perhaps some operators, as well as other interested persons, who are not familiar with the methods used in gas collection and sludge heating. Particularly for the benefit of such persons, brief mention is made of the various pieces of equipment commonly employed and the function of each.

Mention is also made of some of the operating difficulties which have been encountered and the corrective measures which have been taken.

As a possible aid to future designs, operating results concerning gas production and temperature control for several Pennsylvania sewage treatment works near Philadelphia are presented. In several cases,

where sufficient data are available, the heat transfer coefficients of the heating coils in the digestion tanks also have been computed and are included as a part of this paper.

For the most part the remarks and data here presented are based upon reported operating results for the plain sedimentation sewage treatment works serving the boroughs of Eddystone, Norristown, and Pottstown, and the activated sludge plant situated near Willow Grove which serves the borough of Hatboro and the township of Upper Moreland.

Equipment Used

Sludge digestion tanks may be equipped with either fixed or floating covers. In either case, the flow of gas through the gas collecting system is dependent upon the production of a sufficient volume of gas to create a gas pressure in the digestion tank great enough to overcome the various pressure losses through the collecting system.

In some instances where fixed covers have been used, gas holders have been installed not only to provide storage for gas and thus make possible its more complete utilization, but also to provide a constant pressure in the digestion tank when the holder is in a floating position.

Gas Collection Equipment.—The equipment commonly provided for the collection and burning of the gas consists of a gas dome on the digestion tank, the gas piping, condensate trap, gas meter, pressure relief trap, waste gas burner, flame trap, and boiler, together with various boiler appurtenances.

The gas dome may be one of several types but is commonly of metal and cylindrical in form, being set in the digestion tank roof. In many cases, the upper part of the gas dome rests in an annular chamber in which heavy oil is commonly placed to seal the opening and at the same time provides means for relieving the gas pressure if it becomes too great. There are some instances where the seal provided for relieving excess pressure is a distinct unit separate from the gas dome.

It is, of course, necessary to maintain pressure in the digestion tank sufficient to overcome the losses through the gas piping and various pieces of gas equipment, and provide the necessary residual pressure at the gas burners, usually 2 or $2\frac{1}{2}$ inches of water pressure. No less important is the desirability of maintaining positive pressure in the digestion tank at all times to prevent entrance of air, which might produce an explosive mixture. On the other hand, the pressure should not be so great that large quantities of gas are likely to escape through minute cracks in the digestion tank roof. In early installations the depth of seal at the gas dome was commonly not over six inches, and occasionally less, but there has more recently been a trend toward deeper seals.

For the purpose of scum control, some gas domes have been provided with facilities for spraying water into the digestion tank, either through one or more fixed nozzles or through a rotating nozzle of the fish-tail type. In the case of fixed nozzles, the object may simply be to provide water for saturating the scum as a means of control, but in the case of a rotating nozzle it may be arranged with the object of actually moving the scum away from the gas dome. Consideration has also been given to equipping gas domes with a mechanism in the nature of a rake which may be rotated to break up the scum. Regardless of the facilities provided for scum control, it seems a wise precaution to place the gas outlet at an elevation sufficiently above the sludge level to minimize the possibility of scum entering the gas line.

As the gas leaves the digestion tank, it contains a considerable quantity of moisture and also possibly tarry products and corrosive substances which should be removed before the gas passes through the meter, if excessive clogging or even actual disintegration of the meter is to be avoided. The condensate trap, placed at the low point in the gas line ahead of the gas meter, provides a pocket in which the moisture may collect. An overflow or drain is provided for the removal of the accumulated condensate.

At many plants, only one gas meter is provided regardless of the number of digestion tanks, while at some plants a gas meter is furnished for each tank, providing individual records of gas production. The gas meter should be equipped with a bypass to permit ready removal of the meter for repairs.

The pressure relief trap is a device which provides for the escape of gas from the system when it is being produced at a greater rate than that at which it is being burned. It consists essentially of a vertical cylinder of cast iron or other material containing a small amount of water. A connection from the gas line extends into the pressure relief trap to a point below the water surface, and the pressure relief trap is provided with an outlet above the water surface through which waste gas may be conducted to the atmosphere or to a waste gas burner. As long as the pressure in the gas line is less than the submergence of the gas inlet line in the pressure relief trap, there will be no flow of gas into the relief trap; but when a greater pressure exists in the gas line, gas will bubble through the water seal and will pass out through the relief outlet. When no waste gas burner is used, the relief outlet should be extended into the air and should be provided with a turned-down outlet, to reduce the danger of accidental ignition of the gas. The provision of a fine mesh wire screen at the pipe outlet further reduces the danger of explosion.

Perhaps the most important single piece of equipment used on the

gas collection system is the flame trap, provided to prevent the flame from travelling through the gas system from the boiler to the digestion tank and causing a harmful explosion. The explosive character of sludge gas has been dealt with at some length by G. W. Jones[2] and others, and the records of explosions at sewage treatment works, with attendant loss of life as well as property damage, have demonstrated all too vividly the reality of the explosion hazard where gas collection is practiced.

Some designers feel that it is sufficient to provide fine mesh wire screen in the gas line near the boiler to prevent flame travel through the gas system. Jones has pointed out that this device, embodying the principle of the Davy safety lamp, provides excellent protection for stationary or slow-moving flames; but is not absolutely dependable where high velocities and high pressures are developed. A wire screen likewise ceases to be a dependable safety device when it acquires a temperature in excess of the ignition temperature of the gas.

Considerable use has been made at sewage treatment works of flame traps of the release diaphragm type, which seem to provide not only a means of arresting the flame, but an outlet for the liberation of excess pressure which may have developed. This type of flame trap consists of a cylindrical body, frequently of cast iron, closed at the bottom and partially filled with water, with a diaphragm covering the opening in the top. Gas enters through a perforated pipe submerged a short distance under the water through which the gas bubbles into the space above the water. The gas outlet pipe is placed above the water surface. In most of the earlier designs, the diaphragms were of heavy paper, but the use of diaphragms of aluminum or tin foil has received consideration more recently. A suitable shield should be placed above the diaphragm to prevent damage to it, and to prevent harm to workmen by flames issuing through the diaphragm opening. It is highly important to maintain the proper amount of water in the flame trap at all times.

Other types of flame traps have also been developed. One which is in rather common use involves the principle of passing the gas through openings between a number of closely spaced plates submerged in a water seal.

Sludge Heating Equipment.—Although other means of heating sludge digestion tanks have been employed, notably in Germany, the usual method in this country involves the circulation of hot water through pipe coils supported along the inside of the digestion tank walls. At the majority of plants the hot water is supplied at a temperature of approximately 120° F., but successful use of higher initial temperatures without undue caking of sludge on the heating coils has been reported. Walraven,[3] for example, has reported the use of an initial heating water temperature of 155° F. for two years without evidence of incrustation.

The sludge heating equipment should include: hot-water circulating pumps, preferably in duplicate; meters for determining the quantity of heating water circulated through each digestion tank; and thermometers, preferably of the recording type, to determine the temperature in the hot-water feed line and in the return line from each tank, the temperature of the sludge in each tank, and the outside air temperature. If a water meter is not provided for each tank, some other means should be made available for proportioning the flow of heating water to the several tanks, such as a manometer for measuring the pressure loss through a thin-plate orifice in each line.

If accurate temperature data are available and the volume of circulating water is known, it is possible to calculate the total heat supplied to the digestion tank; and, if the quantity of sludge added to the digestion tank is known, the portion of the total heat which is being effectively used for heating sludge may be determined. For control purposes only, some of this equipment is perhaps not absolutely essential; but there are many questions in connection with the heating of sludge which at present are by no means definitely ascertained facts, and unless the basic data are obtained and analyzed we cannot hope to establish the facts.

Construction of Digestion Tanks

In the interests of a clearer understanding of later discussion, it is pertinent to mention that all the sludge digestion tanks here referred to have fixed concrete covers.

There are two digestion tanks at Eddystone, one on either side of the settling tanks, with a common wall between the settling tanks and the sludge digestion tanks. Each digestion tank is 65 ft. 6 in. long, 12 ft. wide, and 10 ft. deep, with a hopper at the outlet end from which sludge is withdrawn. For most of the surface area, the sludge is in contact with the tank roof, but for a distance of 8 ft. 3 in. from the inlet end, the tank roof is 4 ft. higher than elsewhere. The gas dome is located on this raised portion of the roof. Sludge collectors with moving flights are used for mixing sludge and for scraping scum from the lower side of the tank roof. The digestion tanks are exposed above the ground surface a distance of about 4 feet.

Each of the six digestion tanks at Norristown is likewise rectangular in shape, being 90 ft. long and 12 ft. wide, having 4 hoppers in each tank. The hoppers are 5 ft. deep and the maximum sludge depth is 19 feet. Sludge may be introduced at four points in each tank and may be withdrawn from any hopper. A gas chamber 3 ft. 9 in. wide and 2 ft. high extends along the longitudinal center line of each tank and one gas dome

is provided at the mid-point of each gas chamber. The tank roof is about 3 ft. above the ground surface.

The two digestion tanks at the Hatboro-Upper Moreland plant are hoppered-bottomed, each tank being 24 ft. by 20 ft. in plan with a center depth of 21 ft. 3 in. and a side depth of 13 ft. 3 in. A gas dome is located in the center of each tank roof. An overflow weir controls the sludge level. The upper 5 or 6 feet of each digestion tank are exposed to the air.

Two circular digestion tanks, each having a diameter of 45 ft. and a side depth of 19 ft., are in use at Pottstown. The roof slopes upward from the outside of the tank toward a concrete gas dome at the center. Oil seals are provided at two manholes in each tank roof. The tanks contain rotating sludge scrapers and scum breakers. An adjustable overflow weir in each tank determines the maximum sludge level. Except for the gas domes and manholes, these tanks are completely covered with an earth fill.

Difficulties Experienced

Some difficulties have been encountered with digestion tanks having fixed covers. With few exceptions, the experiences at the several plants referred to have been much the same.

One of the troublesome features of such tanks has been the difficulty of preventing the oil seal from being blown out of the gas dome due to a pressure increase when sludge is pumped into the digestion tank. Even the withdrawal of supernatant liquor or digested sludge at the same time as sludge is being added does not overcome the difficulty when constant-speed sludge pumps are used.

After such trouble at Eddystone, a small gas line leading from the gas dome was connected to a home-made U-gauge placed at a point near the switch controlling the sludge pump. The supernatant-liquor decanting valve is opened before sludge pumping is started and when the pressure as indicated on the U-gauge drops about 3 inches, the sludge pump is started and allowed to run only until the pressure builds up to 3 inches. By such intermittent operation of the sludge pump, the rate of sludge discharge into the tank and the rate of supernatant liquor withdrawal from the tank are to some extent balanced and loss of the oil seal is prevented, but this practice cannot be considered a completely satisfactory answer to the problem. At another plant the gas dome cover is propped open when sludge is being pumped into the tank.

Pumping of sludge into digestion tanks has also caused oil to be blown out of the seals at the Hatboro-Upper Moreland and Pottstown plants, where there are overflow weirs on the digestion tanks. It is reported that some oil has even been blown out of the gas domes at the

Hatboro-Upper Moreland plant when no sludge was being added. The operator has found that by cracking the valve on the gas meter bypass he can reduce the flow resistance sufficiently to prevent loss of oil from the seals.

At Norristown the practice has been adopted of using oil seals only during the winter months and water seals during the warmer months.

Young and Phillips [4] have reported trouble with keeping the oil seal in the gas dome at Meadville, as a result of which the depth of the seal was increased to 12 inches.

Of considerably more importance, at least from the standpoint of safety, has been the great difficulty of drawing sludge from fixed-roof digestion tanks without purposely allowing air to enter the tanks, and thus perhaps creating an air and gas mixture of explosive proportions.

The reason for this difficulty is not hard to understand when consideration is given to the pressure change which takes place within a fixed-roof tank when sludge is withdrawn. Let us suppose for example, a digestion tank in which we have a certain weight of gas occupying a volume of 100 cu. ft. at a pressure of 4 in. of water, or 0.14 lb. per square inch. According to Boyle's Law, with temperature constant the volume of a given weight of gas varies inversely as its absolute pressure, or $P_1V_1 = P_2V_2$. Suppose that we wish to withdraw 300 cu. ft. of sludge, in which case the volume occupied by the given weight of gas will become 400 cubic feet. In terms of absolute pressure, P_1 will equal 14.70 plus 0.14, or 14.84 lb. per square inch.

Therefore,

$$P_2 = \frac{P_1V_1}{V_2} = \frac{(14.84)(100)}{400}$$

$P_2 = 3.71$ lb. per sq. in. absolute pressure, equivalent to a vacuum of 10.99 lb. per sq. in., or 25.3 ft. of water.

Even if a hydrostatic head of 8 ft. is normally available for sludge withdrawal, it is readily apparent that under such circumstances sludge cannot be withdrawn from the tank unless air or gas is allowed to enter the tank to destroy the partial vacuum which has been created.

At the Hatboro-Upper Moreland plant, the earlier practice was to remove the gas dome while sludge was being withdrawn, but it is reported that so much air entered the tank that the gas would cease to burn and would not burn well for a long time thereafter. The present practice is to remove the valve stem from the line connecting the main gas line with the gas dome of the tank from which sludge is to be drawn, stuff a rag in the outlet side of the valve, thus allowing air to enter the digestion tank but preventing its entrance to the main gas line. Gas from the other tank continues to burn as usual and at the end of the sludge withdrawal

operation, the rag is removed from the valve opening, the valve stem is replaced and the gas connection is again placed in service. At that point the gas flame may go out, but normal operation is possible much sooner than when the gas dome is removed.

It is further reported that if the gas dome is removed only until the sludge starts to flow from the withdrawal line and is then replaced, the oil seal is sucked out of the gas dome into the digestion tank.

At some plants the necessity of admitting air may be avoided by withdrawing digested sludge and adding fresh sludge simultaneously, but such procedure is not practical in all cases.

The best solution of the problems raised by the foregoing difficulties seems to lie in the use either of floating covers, or of gas holders where fixed covers are used. In the latter case, the gas piping between the digestion tank and the holder should be so arranged that withdrawal of sludge from the digestion tank will be accompanied by flow of gas from the holder to the digestion tank. When a gas holder is used, careful consideration should be given to the importance of purging the holder of air before it is placed in service, in order to avoid the creation of an explosive mixture of gas and air.

Freezing of moisture in exposed gas lines has been known to occur at several plants. The operator at the Norristown plant reports that ice crystals form on the inside of a short section of pipe adjoining the gas dome and, if not disturbed, will accumulate to such an extent in about two months that only a very small hole remains through which gas can flow. At the Hatboro-Upper Moreland plant, freezing is said to have been experienced only at the valves on the gas lines, and is now prevented by building a box around each valve in the winter and filling it with manure.

The flame trap at the latter plant, which is of the diaphragm release type, is on the roof of the boiler house. Packing of manure around the sides of the flame trap has apparently been sufficient to prevent freezing of the water seal.

Experience has also indicated that condensation may cause sufficient water to collect in the oil seals around the gas domes to cause freezing of the seals during the winter months, unless the water is occasionally removed.

As an indication of the large amount of gas which may escape through cracks in digestion-tank roofs, it is said that gas collected at Norristown, during times when the tank roofs were covered with ice, has amounted to two and one-half times the normal metered gas yield at other times. There is, moreover, definite evidence of gas leakage around valve stands on the digestion-tank roofs.

Disintegration of gas meters due to corrosive substances in the gas

has been experienced at several plants, and formation of deposits on the boiler sections and in the boiler stack, due to condensation, is a frequent cause of considerable trouble.

In cases where the gas line at the gas dome is not far above the sludge level, violent gassing or foaming has been known to result in sludge filling the gas lines and even entering the gas meter and flame trap.

Experience has shown that heating coils in digestion tanks may float off of their supports if they are not securely fastened in place.

Gas Production

A large amount of data has been made public concerning the amount of gas produced by digesting sludge. The reported results cover a wide range of values, with daily gas yields as low as 0.21 cu. ft. per capita from Imhoff tanks and yields as great as 1.42 cu. ft. per capita from separate sludge digestion tanks. Rudolfs [5] has stated that the gas yield to be expected from domestic sewage sludge under practical conditions, with proper control and good operation, will probably vary from 0.60 to 0.75 cu. ft. per capita per day.

Records of the quantity of gas collected from the separate sludge digestion tanks at Eddystone for the years 1932, 1933, and 1934 indicate an average gas yield of 1070 cu. ft. per day. On the basis of an estimated equivalent domestic population of 2700 persons, the gas yield would be 0.40 cu. ft. per capita per day. These digestion tanks were, however, heated only during the first five months of 1932 except for occasional subsequent periods of short duration. The average sludge temperature for the three-year period was 59.5° F. Table I shows by months the quantity of gas collected for the three years, together with the monthly average sludge temperatures. The greatest quantity of gas collected in any month was during June, 1934, when the average gas yield was 0.68 cu. ft. per capita per day and the average sludge temperature was 85.7° F.

Comparison of the gas yields with the sludge temperatures does not always show a proportionate variation but there seems to be a trend toward higher gas yields at the higher temperatures. During some of the cold winter months gas production drops very low.

At the Hatboro-Upper Moreland plant, where fairly high sludge digestion temperatures have been maintained, the measured gas production for the years 1933 and 1934 has averaged 2300 cu. ft. per day. The number of sewer connections is rather definitely known and for the period under consideration averaged about 545 connections. At five persons per connection, a tributary population of 2725 persons is indicated. On a per capita basis the gas production for the two years averaged 0.84 cu. ft. per day, with the maximum monthly yield occurring in May 1934, when the monthly average was 1.19 cu. ft. per capita per

day. Monthly average gas yields and sludge temperatures for the Hatboro-Upper Moreland plant during the years 1933 and 1934 are shown in Table II. The continual change in the population indicated in the table is due to the fact that connections were being made almost

TABLE I.—*Gas Production from Separate Sludge Digestion Tanks at Eddystone, Pa.*

Month	Days of Record *	Gas Collected Cu. Ft.		Per Capita Per Day †	Average Sludge Temp. ° F.
		Monthly Total	Daily Avg.		
1932					
Jan.	11	8,400	760	0.28	58.5
Feb.	29	34,900	1200	0.44	57.4
March	31	41,800	1350	0.50	59.0
April	30	34,900	1160	0.43	65.5
May	31	40,700	1310	0.49	76.5
June	30	33,100	1100	0.41	85.4
July	31	34,600	1120	0.42	90.5
Aug.	31	30,000	970	0.36	79.2
Sept.	30	30,200	1000	0.37	67.6
Oct.	31	44,800	1450	0.54	55.9
Nov.	30	31,000	1030	0.38	42.8
Dec.	27	26,100	970	0.36	35.2
Total	342	390,500			
Average			1140	0.42	64.5
1933					
Jan.	31	21,000	680	0.25	35.3
Feb.	28	16,200	580	0.22	33.1
March	31	22,700	730	0.27	35.5
April	30	28,500	950	0.35	47.2
May	26	19,400	750	0.28	58.0
June	28	31,400	1120	0.42	69.6
July	31	43,700	1410	0.52	71.0
Aug.	29	31,600	1090	0.40	72.0
Sept.	18	13,200	730	0.27	65.6
Oct.	31	29,900	960	0.36	54.3
Nov.	30	29,200	970	0.36	39.8
Dec.	31	36,000	1160	0.43	36.4
Total	344	322,800			
Average			940	0.35	51.6

* Days of record applies only to gas yield.

† Per capita gas production is based upon estimated equivalent domestic population of 2700 persons.

TABLE I.—*Continued*

Month	Days of Record *	Gas Collected Cu. Ft.		Per Capita Per Day †	Average Sludge Temp. ° F.
		Monthly Total	Daily Avg.		
1934					
Jan.	31	38,500	1240	0.46	36.8
Feb.	7	4,700	670	0.25	33.4
March	31	24,500	790	0.29	43.2
April	30	27,700	920	0.34	55.8
May	31	41,500	1340	0.50	70.3
June	30	55,100	1840	0.68	85.7
July	31	44,600	1440	0.53	87.7
Aug.	17	17,800	1050	0.39	80.2
Sept.	14	21,800	1560	0.58	74.7
Oct.	31	34,000	1100	0.41	64.5
Nov.	30	30,400	1010	0.37	54.4
Dec.	31	20,300	650	0.24	45.2
Total	314	360,900			
Average			1150	0.43	63.2
3-Year Total	1000	1,074,200			
Average			1070	0.40	59.5

constantly to the sewer system, which was constructed at about the same time as the sewage treatment works. During the initial period of gas production, extending from September 11 to December 8, 1932, the daily

TABLE II.—*Gas Production from Separate Sludge Digestion Tanks at Hatboro-Upper Moreland Sewage Treatment Works*

Month	Days of Record*	Gas Collected Cu. Ft.		No. of Sewer Connections	Population †	Gas Cu. Ft. per Cap. per Day	Average Sludge Temp. ° F.
		Monthly Total	Daily Avg.				
1932							
Sept.	20	19,700	985	304	1520	0.65	
Oct.	31	36,700	1180	314	1570	0.75	
Nov.	30	21,200	710	322	1610	0.44	64.3
Dec.	8	8,300	1040	332	1660	0.63	56.9
Total	89	85,900					
Average			970	317	1585	0.61	57.7

TABLE II.—*Continued*

Month	Days of Record*	Gas Collected Cu. Ft.		No. of Sewer Connections	Population †	Gas Cu. Ft. per Cap. per Day	Average Sludge Temp. ° F.
		Monthly Total	Daily Avg.				
1933							
Jan.	24	25,400	1060	350	1750	0.61	56.3
Feb.	28	33,300	1190	373	1865	0.64	56.7
March	31	47,600	1530	411	2055	0.74	63.5
April	30	60,200	2010	451	2255	0.89	74.8
May	31	74,000	2390	468	2340	1.02	85.5
June	30	71,100	2370	491	2455	0.96	95.6
July	31	59,900	1930	513	2565	0.75	87.5
Aug.	31	75,300	2430	526	2630	0.92	88.9
Sept.	30	64,200	2140	534	2670	0.80	86.9
Oct.	31	63,500	2050	539	2695	0.76	84.1
Nov.	30	71,200	2370	552	2760	0.86	81.1
Dec.	31	67,900	2190	563	2815	0.78	75.2
Total	358	713,600					
Average			1990	480	2400	0.83	78.1
1934							
Jan.	31	66,000	2130	570	2850	0.75	69.7
Feb.	28	56,000	2000	572	2860	0.70	66.4
March	31	75,500	2440	572	2860	0.85	68.8
April	30	95,800	3190	578	2890	1.10	74.2
May	31	106,900	3450	579	2895	1.19	87.4
June	30	91,100	3040	587	2935	1.04	94.7
July	31	71,300	2300	595	2975	0.77	97.4
Aug.	31	81,300	2620	621	3105	0.84	87.6
Sept.	30	66,000	2200	643	3215	0.68	85.6
Oct.	31	69,600	2250	666	3330	0.68	86.0
Nov.	30	71,500	2380	672	3360	0.71	81.5
Dec.	31	96,500	3110	672	3360	0.92	77.0
Total	365	947,500					
Average			2600	610	3050	0.85	83.7
1933–34							
Total	723	1,661,100					
Average			2300	545	2725	0.84	80.9

* Days of record applies only to gas yield.

† Tributary population is based on estimate of 5 persons per sewer connection.

average gas production was about 0.61 cu. ft. per capita. Sludge temperatures are available for only about one-half of the time between September 11 and December 8, 1932, the average for the period of record being 57.7° F., as compared with an average sludge temperature of 80.9° F. during the years 1933 and 1934.

At Pottstown separate gas meters make it possible to determine the quantity of gas produced in each digestion tank. During the year 1934 the average daily yield from Tank 1 was 3650 cu. ft. and from Tank 2, 3430 cubic feet. The total quantity of gas produced averaged 7080 cu. ft. per day. Accurate data regarding the number of persons now served by the plant are not available, but on the basis of the best information at hand the tributary population is estimated to be in the neighborhood of 6000 persons. For this population, the average gas yield approaches 1.2 cu. ft. per capita per day. The greatest monthly gas yield occurred in November and was equivalent to a daily average of 8460 cubic feet. The average sludge temperatures for the year were 76.1 and 77.5° F. for Tanks 1 and 2, respectively. Table III shows the gas yields and sludge temperatures at Pottstown by months for the year 1934.

Insofar as it may have a bearing on the design of gas lines and gas

TABLE III.—*Gas Production from Separate Sludge Digestion Tanks at Pottstown*

Month	Days of Record	No. 1 Digestion Tank			No. 2 Digestion Tank			Total Gas Production	
		Gas Collected Cu. Ft.		Avg. Sludge Temp. ° F.	Gas Collected Cu. Ft.		Avg. Sludge Temp. ° F.		
		Monthly Total	Daily Avg.		Monthly Total	Daily Avg.		Monthly Total	Daily Avg.
1934									
Jan.	31	100,400	3240	69.2	115,500	3730	70.4	215,900	6970
Feb.	28	103,900	3710	72.7	92,300	3300	72.7	196,200	7010
March	31	104,000	3360	73.5	85,000	2740	74.2	189,000	6100
April	30	92,800	3090	74.8	84,700	2820	74.6	177,500	5910
May	31	100,100	3230	73.7	105,100	3390	73.9	205,200	6620
June	30	107,500	3580	72.6	107,800	3590	73.1	215,300	7170
July	31	104,000	3360	78.6	103,500	3340	78.6	207,500	6700
Aug.	31	102,800	3320	79.7	101,300	3270	80.1	204,100	6590
Sept.	30	124,900	4160	82.8	106,800	3560	84.2	231,700	7720
Oct.	31	139,200	4490	79.0	115,000	3710	80.2	254,200	8200
Nov.	30	133,300	4440	82.8	120,700	4020	83.1	254,000	8460
Dec.	31	117,100	3780	84.1	114,000	3680	84.5	231,100	7460
Total	365	1,330,000			1,251,700			2,581,700	
Average			3650	76.1		3430	77.5		7080

collection equipment, it is worth noting that the maximum daily gas yield may be at least as great as two and one-third times the average daily production over a year's time. On the basis of some hourly readings of the gas meter at Eddystone, made December 11 to 15, 1933, it further appears that the maximum hourly rate of gas production may reach 175 per cent of the average hourly rate, or over four times the average daily rate.

Sludge Heating

Experience at Antigo, Wisconsin, one of the early sludge heating installations, indicated that the use of a header in the digestion tank to supply a number of heating pipes is likely to result in unequal distribution of heating water to the several pipes. The usual practice now is to arrange the heating coil in the form of a continuous spiral so that there is positive assurance of flow throughout the heating pipe.

In many cases the heating coils have been placed in a position quite near the tank walls, but there seems to be some merit to the claim that placing the pipes two feet or so from the tank wall will better allow convection currents to sweep around the pipes and perhaps result in a greater transfer of heat to the sludge.

Heat Required.—In the design of the sludge heating system, it is necessary not only to provide for raising the temperature of the fresh sludge to the desired temperature of digestion but also to supply such additional heat as may be necessary to make up for heat losses from the digestion tank to the surrounding air and earth. Because of the lack of specific data on many points which enter into such design, it is necessary to make numerous estimates and assumptions.

Measurements of the temperature of sewage in primary settling tanks indicate that even during the coldest weather experienced in the Philadelphia area, the temperature of the fresh sludge is not likely to go much below 50° F., a value rather commonly assumed as representing the initial sludge temperature.

If it were possible to predict with any certainty the quantity of sludge which would be placed in the digestion tank each day, it would be a relatively simple matter to determine the amount of heat necessary in each digestion tank for raising the sludge temperature to the desired point. Unfortunately, experiences at different plants, even of the same type, have been widely divergent in this respect, due primarily to the varying moisture content of the sludge. Where means are provided for concentrating or thickening sludge prior to its discharge to the digestion tank, there seems to be more hope of predicting how much sludge will be added to the digestion tank each day.

At least in the smaller plants, where as a matter of actual practice all of the day's sludge is likely to be placed in one digestion tank, suitable

recognition of this fact should be made in the design by providing sufficient heating coil in each tank to heat the entire day's sludge production and make up for heat losses from the tank. In plants where there is reasonable assurance that the day's sludge will be divided among two or more tanks, proportionate reduction in amount of heating coil in each tank is justified.

The heat losses from the digestion tank are not at present subject to such accurate determination as the heat requirements for sludge alone. The heat loss through a wall or other body is the sum of the loss through the surface film separating the inside of the wall from the enclosed air, liquid or other substance, the loss through the wall itself, and the loss through the outside surface film separating the wall from the air or other medium surrounding it.

In connection with building construction, numerous studies have been made and results published concerning the film coefficient in still air and at various wind velocities, but there seems to be a scarcity of data for conditions comparable to those commonly found in the case of sludge digestion tanks, with a rather viscous liquid on the inside and earth, ground water, and air around the outside. Even with respect to the thermal conductivity of concrete, of which digestion tanks are most often constructed, there is a wide range of values depending, among other factors, upon the density of the concrete.

The heat losses from the tank will likewise be influenced to a considerable degree by the provisions, if any, for insulating the tank. The digestion tanks at Meadville [4] are insulated by 3-in. hollow tile seconds placed outside the tank walls and plastered with ½-in. of cement mortar. At Coatesville the digestion tank roofs are constructed of 10-in. load-bearing hollow tile covered with 2 in. of concrete, and the exposed portion of the tank walls are insulated to a point about 2 ft. below the ground surface with a 4-in. brick wall, forming a 2-in. air space between the brick wall and the outside of the concrete tank wall. Walker [6] has reported the use at Carlisle of cinders surrounding the digestion tanks for a thickness of 16 to 18 in. between the tank walls and the earth fill.

Coefficient of Heat Transfer.—After determining the amount of heat which must be supplied to each digestion tank to maintain the desired temperature, the designer's next problem is to decide how much heating pipe must be furnished. This will depend upon the degree to which the heating coil is able to transfer heat from the hot water within the coil to the sludge, and may be represented by the heat transfer coefficient, or the amount of heat expressed in B.t.u. which will pass through each square foot of pipe surface in one hour for each degree Fahrenheit temperature difference between the heating water and the sludge.

Information on this point which would properly be applicable to the

special conditions found in sludge digestion tanks was extremely limited when some of the early sludge heating installations were designed. As a result of the lack of specific data, heat transfer coefficients ranging from 3 to 30 B.t.u. per hr. per sq. ft. per deg. F. temperature difference, have been used or recommended. In the past several years, some data along this line have been published. It does not seem reasonable to expect that any one heat transfer coefficient is the correct one for all conditions, and this opinion is verified by the fact that published data thereon cover a rather wide range of values as shown in Table IV.

TABLE IV.—*Coefficient of Heat Transfer for Pipe Coils in Sludge Digestion Tanks*

Kind of Pipe	Period of Record	Avg. Temp. of Heating Water ° F.	Avg. Sludge Temp. ° F.	Heat Transfer, B.t.u. per Sq. Ft. per Hr. per ° F. Temp. Diff.	Authority and Reference
W. I. (1¼″)	51 weeks	104	71	6.23	Antigo, Wisc.
" " (2″)	1 year	103	80	10.7	Keefer [7]
" " (2″)	1 year		83.7–85.7	9.29–9.73	Keefer [8]
" " (2″)	2 months		89–97	17.7	Young & Phillips [4]
?	?	(Sludge 12% Solids)		11	Walraven [3]
?	?	(Very Thin Sludge)		39	Walraven [3]
C. I. (2″)	4 months	111		7.7	Haseltine [9]
Copper	2.5 years	122–140		10.2–12.3	Heilmann [10]
Tinned Copper		176		3.1	Heilmann [10]

In order to supplement this information, heat transfer coefficients have been computed for the Eddystone and Pottstown sludge digestion tanks.

The Eddystone digestion tanks are provided with 4 turns of 2-in. galvanized wrought iron pipe, spaced 12 in. center to center and supported at a distance of about 6 in. from the tank walls. The lowest coil is 4½ ft. above the bottom and the highest coil is 7½ ft. above the bottom, or 2½ ft. below the tank roof. There is a total length of 610 ft. of heating coil in each tank. Circulated water is metered, and the temperatures of ingoing water, outgoing water, and sludge are measured by recording thermometers.

The Eddystone computations cover a total of 101 days, extending from January 1, 1932 to April 17, 1932 except for the seven days from January 12 to 18, inclusive, for which records are not available. These data, shown in Table V, refer to Tank 2. During this period the average temperature of the sludge was 59.2° F. and the temperatures of ingoing

TABLE V.—*Monthly Summary of Sludge Heating Data for Separate Sludge Digestion Tank 2 at Eddystone, Pa.*

Month	Days of Record	Average Temperatures ° F.				Heating Water Used		Heat Supplied		Log. Mean Temp. Diff.	Heat Transfer Coefficient
		T_s	T_h	T_c	$T_h - T_c$	GPD	Lb. per Hour	B.t.u. per Hour	B.t.u. per Sq. Ft. per Hour		
1932											
Jan.	24	59.4	96.4	68.7	27.7	6,250	2170	60,050	158	20.1	7.9
Feb.	29	57.4	88.9	69.7	19.2	9,400	3260	62,700	165	20.5	8.1
March	31	59.0	96.2	73.2	23.0	10,420	3620	83,200	219	23.9	9.2
April	17	62.7	83.9	69.6	14.3	7,810	2710	38,800	102	12.7	8.1
Total	101										
Average		59.2	92.1	70.5	21.5	8,700					8.4

Average velocity in heating coils = 0.59 f.p.s.

and outgoing heating water in the coils were 92.1° and 70.5° F., respectively. The average amount of heating water circulated through the coils was 8700 gal. per day, producing a velocity of 0.59 ft. per second. During this time the average heat transfer coefficient was 8.4 B.t.u. per sq. ft. per hr. per deg. F. temperature difference. The outside surface area of the heating pipe was used and the coefficient was based upon the logarithmic mean temperature difference, as determined by the following equation:

$$\text{Logarithmic Mean Temp. Difference} = \frac{T_h - T_c}{2.3 \log \frac{T_h - T_s}{T_c - T_s}}$$

where T_h, T_c, and T_s are the temperatures in degrees Fahrenheit of ingoing heating water, outgoing heating water, and sludge, respectively.

At Pottstown each digestion tank contains 3 turns of 1½-in. galvanized wrought iron pipe, spaced 3 ft. center to center, and providing 420 lineal feet of heating coil per tank. The coils are located approximately 20 to 50 per cent of the tank depth above the bottom. Circulated water is individually metered and recording thermometers measure the temperatures of ingoing and outgoing water. Sludge temperatures are measured about twice each week.

The heat transfer has been computed for each tank for the period between December 12, 1933 to March 31, 1935. Due to the fact that

there were some occasions, notably during the month of May, 1934, when the records were incomplete and could not be included, the computations actually cover a period of 371 days. During this time the average sludge temperatures of Tanks 1 and 2 were 77.7° and 78.4° F., respectively, the ingoing heating water had an average temperature of 118.4° F., and the temperatures of the water in the heating coils as it left the tanks were 93.5° and 93.0° F., respectively. As indicated in Tables VI and VII, the heat transfer varied by months from a minimum

TABLE VI.—*Monthly Summary of Sludge Heating Data for Tank 1 at Pottstown*

Month	Days of Record	Average Temperatures ° F.				Heating Water Used		Heat Supplied		Log. Mean Temp. Diff.	Heat Transfer Coefficient
		T_s	T_h	T_c	$T_h - T_c$	GPD	Lb. per Hour	B.t.u. per Hour	B.t.u. per Sq. Ft. per Hour		
1933											
Dec.	20	59.2	128.1	83.5	44.6	8,110	2820	125,800	605	42.7	14.2
1934											
Jan.	31	69.2	120.9	85.8	35.1	7,270	2530	88,600	427	30.9	13.8
Feb.	28	72.7	120.7	84.9	35.8	6,790	2355	84,400	405	26.2	15.5
March	27	73.5	120.3	84.9	35.4	6,890	2390	84,600	407	25.1	16.2
April	30	74.8	107.4	83.4	24.0	7,230	2510	60,200	290	18.0	16.1
May		Records incomplete for May									
June	13	74.3	115.1	88.3	26.8	8,890	3090	82,700	398	25.1	15.9
July	15	78.6	118.9	95.1	23.8	10,689	3709	88,200	424	26.7	15.9
Aug.	19	80.9	116.9	94.4	22.5	9,890	3430	77,200	371	23.0	16.2
Sept.	15	83.8	119.8	97.1	22.7	9,620	3340	75,900	365	22.8	16.0
Oct.	22	79.3	117.3	90.2	27.1	8,200	2845	77,100	371	21.7	17.1
Nov.	30	82.8	119.9	96.9	23.0	11,470	3980	91,500	440	23.8	18.5
Dec.	31	84.1	118.1	101.0	17.1	16,280	5650	96,600	465	24.5	19.0
1935											
Jan.	31	84.1	119.7	103.6	16.1	19,180	6660	107,300	516	26.8	19.3
Feb.	28	81.6	117.9	104.9	13.0	24,100	8370	108,900	523	29.3	17.8
March	31	82.6	116.7	103.0	13.7	21,330	7410	101,700	489	26.6	18.4
Total	371										
Average		77.7	118.4	93.5	24.9	12,260					16.8

Average velocity in heating coils = 1.34 f.p.s.

of 13.8 to a maximum of 20.8 B.t.u. per hr. per sq. ft. per deg. temperature difference. In the case of Tank 1 the average coefficient for the period of record was 16.8 and for Tank 2 the average coefficient was 17.4. The average quantity of heating water circulated was approximately

TABLE VII.—*Monthly Summary of Sludge Heating Data for Tank 2 at Pottstown*

Month	Days of Record	Average Temperatures ° F.				Heating Water Used		Heat Supplied		Log. Mean Temp. Diff.	Heat Transfer Coefficient
		T_s	T_h	T_c	$T_h - T_c$	GPD	Lb. per Hour	B.t.u. per Hour	B.t.u. per Sq. Ft. per Hour		
1933											
Dec.	20	58.6	128.1	84.0	44.1	8,810	3060	135,000	649	43.9	14.8
1934											
Jan.	31	70.4	120.9	85.4	35.5	7,060	2450	87,000	418	29.3	14.3
Feb.	28	72.7	120.7	84.9	35.8	6,640	2300	82,600	397	26.1	15.2
March	27	74.2	120.3	84.4	35.9	6,010	2090	75,000	360	23.8	15.1
April	30	74.6	107.4	82.6	24.8	7,085	2460	61,000	293	17.6	16.6
May		Records incomplete for May									
June	13	75.0	115.1	86.2	28.9	7,445	2580	74,500	358	22.7	15.8
July	15	78.4	118.9	94.1	24.8	10,590	3680	91,300	439	26.2	16.7
Aug.	19	81.3	116.9	93.4	23.5	9,220	3200	75,100	361	21.8	16.6
Sept.	15	85.1	119.8	97.5	22.3	9,740	3380	75,400	362	21.7	16.7
Oct.	22	80.9	117.3	89.8	27.5	6,630	2300	63,200	304	19.5	15.6
Nov.	30	83.1	119.9	95.7	24.2	10,650	3700	89,500	430	22.6	19.0
Dec.	31	84.5	118.1	100.8	17.3	16,840	5850	101,200	487	23.9	20.4
1935											
Jan.	31	84.3	119.7	102.9	16.8	19,380	6730	113,100	544	26.1	20.8
Feb.	28	84.2	117.9	104.3	13.6	23,590	8200	111,700	537	26.3	20.4
March	31	83.9	116.7	102.0	14.7	19,660	6830	100,500	483	24.7	19.5
Total	371										
Average		78.4	118.4	93.0	25.4	11,830					17.4

Average velocity in heating coils = 1.30 f.p.s.

12,000 gallons for each tank, indicating an average velocity in the coils of 1.3 ft. per second.

Due to some question regarding the accuracy of the supply water temperatures at Pottstown, the computed coefficients of heat transfer may be a little high.

A word of explanation is in order regarding the method of deriving the average coefficients for the period of record. They are the weighted averages of the coefficients for the individual months and are not equivalent to the results which would be obtained by a single computation based upon the average temperatures and average quantity of water circulated during the period of record. In cases where both the tem-

perature drop of the heating water and the quantity of water circulated fluctuate at the same time through a wide range, it is not mathematically correct to obtain the average value for the heat transfer by multiplying the average temperature drop of the heating water by the average quantity of water circulated. For this same reason, the monthly average coefficients shown in Tables V, VI and VII are likely to be slightly in error due to concurrent fluctuations of temperatures and quantity of water circulated during any single month. However, it was not felt that the greater degree of accuracy obtainable by making daily computations would justify the large amount of work which would thus be required, especially since a superficial examination of daily records showed that in general the fluctuations within a single month were of such a character that they would not greatly influence the monthly average.

The heat transfer coefficient is apparently dependent upon a number of factors, including possibly the size of the heating coil, at least insofar as the pipe thickness may affect the coefficient, the velocity in the heating coil, the extent to which movement of the sludge around the heating coil occurs, due either to convection currents or mechanical stirring, the presence of incrustation on either the inside or outside of the coils, the viscosity of the sludge, and the respective temperatures of heating water and sludge.

It is well to bear in mind that heat transfer coefficients derived from operating data at plants where there is a fixed length of heating coil, as these have been, may not necessarily represent the maximum values obtainable. It is possible that the same amount of heat might be absorbed from the heating water by the sludge with a much shorter length of coil. Such a possibility would seem most likely in cases where the temperature of the outgoing heating water is not greatly in excess of the sludge temperature, as at Eddystone. In other words, it seems conceivable under such circumstances that the temperature of the heating water part way around the coil may be nearly as low as the heating water temperature at the point where it leaves the sludge digestion tank.

Pre-heating Sludge. Since there are few, if any, plants in this country other than the one at Coatesville, Pa., where provision is made for heating sludge prior to its discharge into the digestion tanks, a brief description of the sludge heaters might be of interest even though the plant is not in operation.

Each of the two heaters consists of a horizontal steel shell, 4 ft. 3 in. in diameter, containing seventy-six 4-in. copper tubes. The effective length of each tube is 13 ft. 3 in., and each heater has a heating surface of 1000 sq. ft. The bends at the ends of the tubes are cast as U-tubes in the heads of the heater, which may readily be swung open for cleaning the tubes.

Sludge will be pumped into the bottom of the heater and will make thirty-eight passes through the tubes before it is discharged at the top. Hot water will be introduced at the top of the shell and will be conducted by baffles along the tubes in a direction opposite to the flow of sludge.

The designer estimated a normal capacity of 40 gal. per min. for each heater, based on heating the sludge from an initial temperature of 50° F. to a final temperature of 110° F. It is the intention to provide hot water at an initial temperature of 160° F. and to convey the outgoing water through the coils in the digestion tanks for the purpose of providing heat equivalent to the losses from the digestion tanks.

Conclusions

Consideration of experiences in connection with the operation of separate sludge digestion tanks where gas is collected and sludge is heated, leads to the following conclusions:

In order to avoid the blowing of gas dome seals, the flow of oil from the seals over the tank roofs, the extinguishment of the gas flame in the boiler, and the admission of air, which might form an explosive mixture within the digestion tanks, it is advisable to provide gas holders, floating covers or other means of limiting gas pressure changes within the digestion tanks.

Insulation of exposed gas lines is a desirable precaution against freezing where cold winters are prevalent.

Gas outlet pipes should be located at a liberal distance above the sludge level in digestion tanks to minimize the possibility of sludge or scum filling the gas lines, meters, and other equipment during periods of violent gassing or foaming.

Disintegration of gas meters by corrosive substances in the gas and the formation of condensate and accumulation of deposits on boiler sections and in boiler stacks are matters which merit thoughtful attention.

Apparently the coefficient of heat transfer from hot water within heating coils to sludge outside the coils fluctuates when there are variations in the rate of heating water circulation, in the temperatures of heating water and sludge, and in the viscosity of the sludge. Further study should be made to determine the extent to which the heat transfer coefficient is affected by these and other variable factors. There is also need for data regarding heat losses through concrete walls of sludge digestion tanks.

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DISCUSSION

BY ELTON D. WALKER

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I find myself in agreement with the author in most of his statements though differing with him in one or two matters, of perhaps minor importance, and my discussion will, in general, consist of supplementary statements.

I think that there can be no argument as to the importance of the flame trap and that one should be placed on the gas line running to the boiler and also on the line to the waste gas burner, with no fixtures, except possibly a drip, between the flame trap and the place where the gas is burned.

In my opinion there should be a separate circulating pump for the heating coil in each digesting tank to provide for the control of the heating of each tank individually. Sometimes one tank will show a different behavior from the others and if each has its own pump the coils in one tank can be furnished more or less hot water according to the needs of the tank by varying the setting of the thermostat controlling the circulating pump. In general, this method is easier to apply than those which depend upon turning valves by hand to throttle the flow in some lines and increase the flow in others. Of course, thermostatically controlled by-passes are also possible but the individual circulating pumps possess some advantage over this.

Freezing of moisture in the gas lines from the domes of the older style floating covers has been reported in some cases, but this is avoided in the later designs in which the gas line is entirely inside the tank until it passes through the concrete side wall into the ground.

The author has not stated one thing that would be of interest in connection with the amount of gas produced per capita—that is, the practice regarding the pumping of sludge into the digestion tanks, whether this is done daily or at less frequent intervals. In a paper by Fair and Kline, *Sewage Works Journal*, Volume 1, page 14, it was brought out that the age of the sludge when introduced into the digestion tanks has an effect on the rate of gas production.

Trouble due to condensation on the boiler plates, mentioned by the author, can be reduced or overcome by maintaining a higher temperature, 160° to 180° F., of the water in the boiler. A thermostatically controlled valve on a by-pass around the boiler, between the return and flow line will provide for the maintenance of the desired lower temperature of the water going to the heating coils. In some cases, it may be necessary to introduce a resistance in the return line between the by-pass and the boiler. This can be done, if required, by putting a thin orifice plate in a flanged joint.

Regarding the corrosion of gas meters mentioned by the author, I would like to ask if these were gas meters made for the purpose and lined with corrosion resisting metal, or whether they were ordinary gas meters not designed for this sort of service.

In connection with the difference of gas production per capita at different places, this is sometimes due to the character and amount of manufacturing wastes and to differences in food habits of the people, as has been pointed out by some investigators.

In connection with the insulation of the side walls of digestion tanks, the fact should be mentioned that adequate drainage should be provided at or below the bottom of the insulation. While that is rather obvious, it has been overlooked in some instances. The author states that at Carlisle cinders are used between the digestion tank walls and the earth fill. To avoid a possible misunderstanding, I wish to bring out the fact that the cinder insulation extends not only through the fill but to the bottom of the walls.

The tables of results at different plants given by the author are interesting. One question arises as to the location of the pipe coils with respect to the zones of active digestion and of digested sludge. While the distances from the bottom of the tanks are given, information is lacking as to the depth of completely digested sludge. This last would depend in part on the frequency of withdrawal to the drying beds. As pointed out by Mr. Queer in his paper "Heat Transmission in Sludge," *Sewage Works Journal*, Volume 5, page 937, the heat transmission coefficient is materially affected by this factor. In case anyone compares the coefficients given by Mr. Queer with those given in Mr. Kinsel's paper, it should be noted that Mr. Queer's coefficients are not overall,

as are those given by Mr. Kinsel, but are between the outer surface of the pipe and the sludge. Overall coefficients can be computed, if desired, from the data given in Mr. Queer's Table II.

It is hoped that the operators who may report results of similar tests will include a statement of the location of the heating coils with reference to the zone of active digestion and with respect to the side walls, in addition to the horizontal and vertical distance between successive turns of the pipe in the coils. Knowledge of the velocity of the water in the heating coils is also desirable. I appreciate that the probable reason that Mr. Kinsel has not given us all this information regarding each of the plants on which he has reported is the fact that it is not available in the records.

The author mentions that the thickness of the pipe in the heating coils affects the coefficients of heat transfer. While this is true it does not amount to much practically. The difference in thickness between one-inch and two-inch pipe, for instance, would affect the coefficient by a small fraction of one per cent. The internal resistance of a two-inch pipe would ordinarily be less than one-tenth of one per cent of the total. The surface factors are of much more importance and depend upon the smoothness of the surface of the pipe.

The author is to be commended for his excellent paper and his service to engineers and operators in presenting it at this meeting. While the data brought together by the author are valuable, even greater value may result if this paper stimulates operators to collect and report similar data from other plants.

BEAUTIFYING THE SEWAGE TREATMENT PLANT*

By Lewis E. Burnside

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It is only within the last few years that designers and owners of sewage treatment works have included in new designs, or in improvement to existing plants, any decent provision for beautification of these works. As late as 1928 such practice was the exception in Pennsylvania but I believe that in the case of new design in this state for the past two or three years it is now almost the rule. Much of the credit for this advance is due the engineering staff of our State Department of Health who have been consistently recommending the measure throughout the state.

If beautification be good business for a new plant it is just as good for an old one and in fact, as a matter of business economics, it is even more important in the case of an old plant.

There are several sound reasons which justify the beautification of sewage treatment works sites, chief of which are the psychological effect and business economy, the latter factor being dependent on the former, and the two constituting the cause and effect in the case, as I shall bring out in this presentation.

Because of the universal repugnance toward all matters pertaining to sewage and the lack of general knowledge by the public regarding modern methods of treatment, the impression of those not acquainted with the facts is that a sewage treatment works is a place where only odors and sights entirely obnoxious are everywhere in evidence, a place which only scavengers can tolerate, and one to be avoided by all self-respecting persons.

It was very largely the unholy appearance and odors given by the stream which formerly carried the sewage through or by our municipalities, rather than the edict of state government, that influenced the citizens to vote favorably for a bond issue providing funds to remove from their midst this intolerable nuisance. After this had been accomplished, the imagination of Mr. and Mrs. John Public pictures the sewage disposal plant as one huge cesspool, into which is dumped the combined sewage of the community, with an attendant multiplication of the slime and stench formerly common to the polluted open-sewer stream.

It is, therefore, natural that the urban public desires the treatment works to be far removed from their zone of life—the farther the better.

* Presented before the Ninth Annual Conference of the Pennsylvania Sewage Works Association, State College, June 25, 1935.

Also, that any proposal to construct it within the surroundings or sight of any part of the community brings violent protest from the immediate inhabitants about the proposed site, in which they are supported by the sympathy of their townsmen and even by the courts.

This often causes consternation to the well laid plans of the designing engineer, who has labored in accordance with his creed to place the works at the location which entails the least cost for the entire scheme.

We here know that no well designed and properly operated sewage treatment works gives any offense to eye or nose outside its own grounds and seldom within them, nor is there any excuse for odors from treatment works. In the event either or both these faults are evident, they can and should be eliminated.

The designing engineer, the city engineer, or the operator, can succeed in destroying the prejudice against the sewage treatment works by applying to it and its site some beautification—one which whether simple or elaborate is attractive—and can thus reduce the objections to a minimum. This is not camouflage by any means but is an application to public structures of the same principle of pleasing design and appointments that is now commonly the rule in the furnishings and finish of bath rooms in our private homes.

It is a well known and accepted fact that the sense of sight is our principal or dominating sense, and so influences all the other senses. If a thing be beautiful to the sight then the pleasure obtained by the eye overrules any minor offense which might adversely affect the other senses.

Landscaping the grounds about a disposal plant with lawns, trees, and shrubbery, even modest in extent, soon converts hostile objectors to appreciative neighbors who, as self-appointed press agents, bring others to see and learn in surprised amazement that the place they thought should be shunned is really a quite pretty and altogether sanitary area where white men, who are both clean and intelligent, work and serve in an important task.

The landscaping about a disposal works is neither a difficult nor expensive matter. The many tanks essential for the processes of sewage treatment are of necessity soundly built of enduring materials. The buildings required, usually not more than two or three in number, should be of material just as durable as the tanks and can be built, using brick, stone and tile, in simple, pleasing design with little more cost than plain, bare-faced or ugly structures.

One of the first sewage treatment works in Pennsylvania to put beautification in practice was the Pennypack plant in Philadelphia and I am informed by the Chief Engineer of our State Board of Health, Dr. W. L. Stevenson, who was the engineer in charge of the plant operation at the time, that this had a very material effect in keeping down

the cost of land acquisitions and also the objections of the neighborhoods when additional plants were later constructed in other parts of the city.

The treatment works in my own home town of Sharon, Pa., constructed in 1927 were, I believe, the first in western Pennsylvania to have their site beautified. The works are constructed within the city limits only a block distant from one of our main thoroughfares, solidly built up with residences, upon land which had served for years as a dumping ground, a place of tin cans, tin Lizzies, weeds, decayed vegetation and garbage, and huge rats both quick and dead. This foul waste covered an area of about three acres and had an average depth of six feet. The stench caused by frequently smoldering combustion was most repugnant. The construction here was, at first proposal, seriously objected to by the property owners on the avenue who had long kicked about the dump and assumed the sewage treatment plant would be even worse. They were finally mollified somewhat by our assurance that this would not be that kind of a plant, but on the contrary would eliminate what they had so long detested, and when completed the new works would give them pleasure rather than disgust. It was up to the city, through the writer, to make good and this has been done. The place was transformed by the structures, greenhouse glass-overs, lawns, tree borders, shrubbed banks and corners as though by magic, within a period of two years, to a place of beauty and pride for the city. Visiting officials of neighboring municipalities have come, seen, and gone home and done likewise.

The personnel, including the common labor employed at the works, are also favorably affected and imbued with pride in their place and their work, and are unusually careful to keep everything clean and to get the best possible results of operation.

The experiences of Philadelphia and Sharon are not exceptional and are but two illustrations of many throughout the state which now number enough to prove the rule.

Suggestions for Application of Landscaping

First in importance in landscaping about the work is the attractive appearance of structures. Second, is well graded grounds which may be level or terraced or a combination of the two as best suited to the several structures, but always providing open expanses of lawns. Third, is a pleasing layout of such roadways as are needed for vehicular traffic, which should be along the boundary lines and in curves insofar as possible, not forgetting to provide an adequate parking ground. Footpaths or walks on lines conveniently connecting the several structures, but in such location that will least cut up the lawns, though they thereby lengthen the line of travel, are very important. Native trees should be

planted along the property lines and roads following close to those lines, but such planting is not advisable along roads or paths bisecting the front of the grounds. Shrubs are a wonderful addition to the appearance when planted about the administration or main building and are advisable for surrounding the parking grounds and blank corners. Shrub hedges are advisable and almost a necessity, about some six to ten feet back from the outside walls of settling or Imhoff tanks, when the tops of these tanks are at or near the elevation of the surrounding grounds. These hedges serve the two-fold purpose of concealing from open view the plain tanks with their seldom pretty contents and forming a safety barrier to visitors. Earth should be placed around tank structures whose tops extend some height above the surrounding grounds. The banks should have a slope about one and one-half to one and should be planted with shrubs that will within a very few years completely cover the surfaces. Seeding or sodding such banks with grass is neither successful nor satisfactory, for if heavy rains and frost do not ruin them repeatedly (and both do so in this State) the work of weeding, cutting and maintaining them in decent appearance is burdensome. In front of the shrubbery about the administration building and along the side of the main entering footpath or bisecting road, beds of perennial flowers add greatly to the beauty of the site. A screen or background along the sides and back of the grounds and around open sludge beds is desirable. High shrubs or even perennials, if the extent makes the cost of shrubs prohibitive, will accomplish this mission. This planting conceals unfavorable appearing surroundings, defines the sites and also furnishes the feeling of seclusion which appeals to the sense of privacy and individuality.

Types of Vegetation Adaptable for Use on Grounds

Almost any type of tree, shrub, or perennial flower, which is native to or will thrive in the locality where used, is adaptable for use on the grounds, so it is not necessary or desirable to provide either rare or foreign vegetations. For high shrubbery, privet, honeysuckle, spirea, forsythia, weigelia, mock orange, golden elderberry, or even the common native elderberry; for low hedges and for banks, barberry, snowberry, corral berry, are appropriate. Around the main building, hydrangea or hills-of-snow, Japanese quince, flowering almond, forsythia, bridal wreath, etc. Next to the walls of glass covered sludge beds where low walls are the rule, thick growing perennials, such as the common variety of day lilies or iris are excellent. For screens along the sides and back of the grounds, if shrubs are not possible, a pleasing summer growth can be had with hollyhocks, golden glow, common elderberry, or similar high growing plants. In our beds about the main building we have iris,

delphinium, poppies, cannas, and fall chysanthemums. We find a delight, as do our visitors, in a solid row of zinnias and asters along the front of the hedges which face the entrance view, these two being the only annuals we have tried so far that are easily grown and furnish a profusion of beautiful colors in the fall. My knowledge of horticulture and the time limit permit the mention of only the small number here named of the many varieties that are adapted and available, but includes those that I have successfully used.

It is not necessary to employ a landscape architect to draw up the plans for the site in a small community. The engineer in charge can make up the grading and road layout and the local nurseryman will be glad to advise and assist without fee on the layout and type of vegetation best adapted for the place and, if at all honest, will be better at the job insofar as costs and planting are concerned since it will be a conspicuous advertisement for him.

Many of the flowering perennials can be secured by donations from the citizens of the community at times when they are thinning out their private gardens. All we have—and they are many—were obtained in this manner.

Reasonable Minimum and Maximum Limits of Extent and Cost

In my opinion the minimum extent in landscaping the site consists of well shaped grading, good grass lawns, and trees about the boundaries, the cost of which would be about ½ per cent of the cost of the treatment works. Further landscaping can be made, if wanted, to any degree those in charge may desire, but an extreme can be reached in this phase just as in any other matter. It is not advisable nor in good taste to attempt to elaborate to an extent such as found on a private estate. Enough to dress the structures and grounds in pleasing but not extravagant harmony, with a dash of bright color scattered here and there, screens to conceal the unsightly areas, open lawns at the front and sides of the structures—this is fully sufficient and can be accomplished at not to exceed 1½ to 2 per cent of the cost of the works.

STARTING UP TWO ACTIVATED SLUDGE PLANTS AT LANCASTER, PENNSYLVANIA *

By John F. Laboon

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Starting the operation of a sewage treatment plant is usually attended by serious as well as humorous situations, and starting the two activated sludge type sewage treatment plants at Lancaster was no exception. After taking almost two years to build, the North Plant had sewage turned into it on December 7, 1934, and the South Plant on May 20, 1935.

Both plants are identical in capacity and general design, except for the layout of the various units which were placed in keeping with their relation to each other, and also, with regard to the physical features of the sites. In general, each plant is designed to treat a normal flow of six m.g.d., and consists of interceptor control works, mechanical screens, mechanical grit chambers, incinerator, primary tanks, overflow works to by-pass, head house, aeration tanks, final settling tanks, chlorinating building, digestion and sludge storage tanks, and open sludge beds.

Operation for the first three months was conducted by Mr. A. B. Cameron, chemist for the designing engineers, the J. N. Chester Engineers (now Chester, Laboon, Campbell, Davis, & Bankson), under the direction of the author.

Before sewage was turned into either plant, all pipe lines were tested for leaks and obstructions, and each unit of the plant was cleaned and the mechanical equipment tried out. Usually, winter operation is bad enough, but placing an activated sludge plant in operation during severe winter weather presented a rather difficult task. To allow for difficulties and emergencies, only single units of the screens, primary tanks and digestion tanks were started. The remaining units were utilized only after the aeration tanks and final tanks had been operating successfully, and sludge digestion and gas production had been accomplished on a satisfactory scale.

The interceptor control works, located in a large underground chamber, a quarter mile or so above the plant, had been completed and blocked off many months before, and, therefore, had collected a great mass of putrefying material behind the dam and ahead of the bar screen. A goodly portion of this material washed into the sewer and travelled to the screen house when the bulkhead was removed. At the beginning, the bar screen, with three-inch clear openings, clogged at least once daily,

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due to rags and Kotex pads. This was corrected by removing alternate bars so that the clear opening became six and one-quarter inches. This required only weekly inspection, and operation became satisfactory.

The mechanical screens presented no problem whatsoever. They operated successfully and most satisfactorily from the beginning. The only change made was to remove the screenings collecting trough, to let the screenings fall directly on the concrete floor, where they drained for a while and then were forked into a garbage can for transporting to the incinerator.

Incineration of screenings, grit and greases presented no particular difficulties. Both coal and sewage gas are used as supplementary fuel. Coal in small quantities is used continuously during winter months when gas is required for heating sludge and the buildings, and coal is probably the more economical fuel. Best results are obtained by raking the charred surfaces of dumpings to the next hearth every few minutes, when charging to capacity. Temperatures of 1350° F. and capacities of 400 lb. per hour of screenings, grit, etc. were obtained with gas at the North Plant, and 1700° F. and capacities of 500 lb. per hour were obtained with coal at the South Plant, on test.

Grease collection was difficult at the beginning due to its concentrated character, but this was remedied by doubling the number of flights and drilling four holes in the grease flume, permitting greater dilutions of the grease by the sewage which passed through these holes. Rubber used for the facing of grease-conveying flights failed to function satisfactorily. Galvanized metal facing has improved operation satisfactorily. Whether by design or otherwise, we know not, one of the most unusual features of the operation of the Lancaster plants is the almost total absence of floating specialty goods. Crankcase oil has at times covered the primary tanks. Other trade wastes, such as dye-wastes, material having the appearance of burnt cork, cotton wastes, etc., likewise have appeared at the plants. Not long after the operations started, one of the operators received a cold bath in sewage when he slipped off the icy walls and fell into the primary tank.

The aeration tanks were not placed in operation until primary treatment and sludge digestion had become well established. The sludge digestion tanks were placed in operation one at a time, and filled with water before adding sludge. Lime was added to the raw sludge to maintain a proper pH, and foaming was watched carefully. Rest periods proved to be the best remedy for foaming. The digestion tank held in reserve proved valuable in such cases. However, foaming was controlled by judicious balancing of sludge additions to the sludge already in the tank. Gas collection was not put into practice until satisfactory digestion had been accomplished and the gas holder and piping system had been emptied of air to a certainty.

At one time improper manipulation of valves by one of the operators resulted in the emptying of one tank and overflowing of the other, resulting in the rapid liberation of gas and filling of the gas holder until it hit the stops with a bang. Mechanical gas safety pop-off valves, located in the top of the gas holders, were replaced with an ample oil seal type, which functioned more satisfactorily. Hose, for conveying gas from the top of the digestion tank to the gas holder, froze when sudden changes in temperature occurred, but otherwise no difficulty was experienced, even on extremely cold days. A clogged sludge line when opened, was found to contain a piece of 2 in. by 4 in. lumber.

The aeration tanks were filled to a depth of 12 inches to protect the diffuser plates from freezing. After testing the plate settings for leaks, the tanks were filled and air applied liberally. Air averaged as much as 1.4 cu. ft. per gallon. At first, when shutting down the aeration tanks, it was necessary to manipulate each air-control valve individually, to keep sewage from passing back through the plates, but later the development of activated sludge served to seal the aeration plates when air flow was stopped, thus permitting control of air from the main air valve for each tank located on the operating floor of the building.

Foam resembling soap bubbles collected extensively on the tanks during the early stages of operation. All sludge from the secondary tanks was returned to the aeration tanks until satisfactory activation was obtained. It took three weeks at the North Plant during cold weather, and one week at the South Plant in warmer weather for development of satisfactory activated sludge.

A most unusual thing happened when the muffler located in the main air line caught fire, sent air temperatures on a ride skyward, and caused smoke to pass through sewage and to fill the building when the blower was shut down. The theory advanced for this occurrence was that spontaneous combustion resulted from the contact of oil with the cotton insulating material in the muffler. These mufflers have been replaced with rebuilt ones containing non-burning material, but these in turn are being replaced because this material has begun to powder. All this is being done at the contractor's expense.

The secondary tanks have operated quite successfully, as is evidenced by the extremely low solids content of the effluent. Sludge from these tanks has contained as high as 1.85 per cent solids, consistently, for long runs. At such times, the liquor in the aeration tanks has contained 3500 p.p.m. suspended solids with 17.5 per cent sludge return. The effluent from the secondary tanks contained 8 p.p.m. suspended solids in a 24-hour composite sample. Rapid development of massive, greenish, stringy growths attached to the walls occurred at the beginning of operations, but upon their removal further growth has been retarded.

For some time, everyone was puzzled by the covering of the tanks with a thin, metallic-appearing film, which occurred periodically. Laboratory examination proved this to be inorganic oil which somehow passed through from the raw sewage. The installation of 2 by 4's placed in triangular form at the influent end of the secondary tanks has served to concentrate this material at this point.

Pumping problems were conspicuous by their absence, except when trouble developed with one of the impellers. Upon opening the pump casing, it was found that a pot hook from a lead-melting pot had become lodged in the impeller. It had evidently come into the pump from the sludge line where someone had carelessly left it during construction.

A most unusual event was the overflowing of the sludge-conditioning well with raw sludge, through faulty manipulation of valves by one of the operators. Sludge had built up in the lime room to a depth of three feet, when someone opened the door and allowed the sludge to flow out into the blower room, and down the steps into the basement, where the operator was working the valves. He, thinking he would be drowned, dashed up the steps, bucking the rushing tide, and a fine time was had by all.

A SAMPLING PROCEDURE FOR TRICKLING FILTER INVESTIGATION *

A Preliminary Report

By Russell L. Johnson

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It was suggested in one of the early reports of the Lawrence Experiment Station that the effluent from a trickling filter consists of a mixture of more or less completely purified liquid and practically untreated influent sewage. The proportion of completely treated liquid in the total effluent volume determines the degree of purification as measured by analyses. When the proportion is large, analyses will indicate a good effluent; when small, the reverse will be true. High rates of application decrease the proportion and the effluent is of poorer quality, and vice versa.

Whether this explanation is entirely correct is not of great importance. The essential point is that the so-called efficiency of purification is affected by the rate of application, and varies throughout the day.

The practice of alternate periods of dosing and resting, caused by the common method of applying sewage to the filter by means of nozzles, produces large variations in the volume of effluent over a complete dosing cycle. I consider this variation to be somewhat analogous to the normal fluctuation in amount of sewage treated by a plant during the day. The main difference is that the variation is a matter of minutes instead of hours. And as the quality of effluent changes over the period of a day, it might be suspected that it would be different at different stages of the dosing cycle.

One phase of the present investigation is an inquiry into this possibility. In other words, what variations in quality of effluent may be expected during a dosing cycle?

The object of this paper is to present some of the preliminary findings for inspection and criticism and to outline the several problems involved in working out a practical and accurate sampling procedure for trickling filter investigation.

Procedure

The underdrains of our trickling filter empty into a collecting gutter at one side of the bed. The bottom of this gutter slopes both ways to

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carry all of the effluent to the center before going to the re-sedimentation basins. The samples were collected at this center point. Before taking any samples the concrete was carefully freed from any adhering scum or solids by use of a broom. Each sample was scooped up with a 12-quart pail, taking care to collect liquid from the entire depth quickly and at exactly 2-minute intervals. Seven samples were usually taken, the first at the moment the nozzles began spraying.

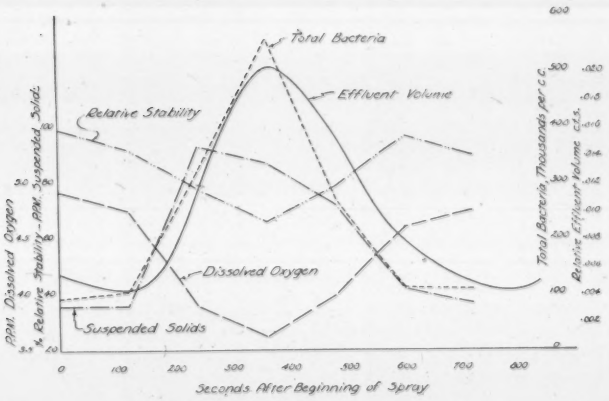
After obtaining a sample it was continuously stirred while withdrawing portions for analysis. The portion for bacterial analysis was placed in a sterile, cotton-stoppered Erlenmeyer flask. The portions to be examined for relative stability and dissolved oxygen content were siphoned into 300-c.c. glass-stoppered bottles.

All analyses were made immediately and in accordance with "Standard Methods of Water Analysis." Most of the chemical analyses, especially that for dissolved oxygen, were run in duplicate. The wide range in bacterial content made it necessary to plate as many as three dilutions for total bacteria and three lower dilutions for acid-producing bacteria (*B. coli*). All dilutions were plated in duplicate or triplicate. Where possible, however, one dilution for each group of bacteria was adhered to in counting.

Results

Only a few of the analytical data are presented in the following table and figure. pH values did not deviate in any one run more than

Variation in Quality of Effluent over Dosing Cycle



one or two tenths from the neutral point and so were not included. The acid count varied greatly over the cycle, as was the case for the other determinations made, alkalinity, ammonia, and nitrate-nitrogen. I feel that more analyses are necessary before these results can be presented. All of the data presented below were obtained on the same samples. The suspended solids analyses were made three times, all others six times.

Minutes of Cycle	P.P.M.		Per Cent Relative Stability	Total Bacteria per c.c.
	Dissolved Oxygen	Suspended Solids		
0	4.83	36	99+	95,000
2	4.75	36	92	104,000
4	3.80	93	78	320,000
6	3.63	87	66	558,000
8	3.99	72	79	272,000
10	4.60	42	96.5	110,000
12	4.76	37	90	108,000

Other Problems

Another phase of the investigation has received quite some attention. This involves working out a method for collecting a composite sample over a single dosing cycle.

One question deserving study is the matter of the detention period of sewage in the filter. How much time lag should be allowed between sampling the influent and effluent to warrant a strict comparison of their analyses?

A fourth phase of the investigation is also contemplated. Due to the imperfect distribution of sewage on the surface of the bed by nozzles, all parts of a section through the bed do not receive equal amounts of sewage. It has been found that the quality of sewage collected at any one level across this section changes with the distance from the nozzles. I believe that similar variations in the amount of film and its contained micro-organisms will be found as well.

The whole investigation may be said to have one main purpose. How can accurate results be obtained in our routine and research analyses with the minimum expenditure of time, labor, and money? The answer to this question—and the results already presented will bear me out—will be found in taking representative samples for analyses. No matter how painstakingly an analysis is made, the result is only as good as the sample.

Acknowledgments

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CHEMICAL PRECIPITATION *

By Michael J. Blew

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A study of current literature shows plainly that at the present time sanitarians are riding the crest of a wave of interest in chemical precipitation of sewage. It is well to remember that chemical treatment in its present form is not out of the experimental stage. It has been stated many times that improved methods of sludge removal, improved chemicals, improved chemical control, and better understood methods of operation, make modern processes superior to the older types.

If these things are true, this present wave of experimentation will leave a valuable and permanent mark on sanitary science.

Chemical methods when used with intelligence are apparently capable of producing a higher degree of treatment than has been attributed to them in the past twenty years. There are two distinct fields where these methods apply. The first is where the process stands entire and complete as a distinct competitor of biological processes, and the second is as an auxiliary to existing processes or as a temporary measure during time of peak loads. It is well, therefore, to judge the present investigations with one eye on past performances.

The use of chemicals to aid precipitation of sewage solids and increase the degree of purity of effluents dates from about 1760. In England in 1762 (Deboissieu) the first British patent was taken out. From that time experimentation proceeded rapidly and patents were issued by the hundreds. The peak was reached between 1880 and 1890 with the advent of biological methods. Sanitarians at that time were tired of constantly fighting the sludge problem of chemical precipitation, which, incidentally, should not be a problem today. The demand for sewage treatment of any sort did not appear in America until after chemical methods of treatment were on the decline in England, so that only a few plants were built here. The principal ones were at Providence and Worcester. All of the older type plants have been abandoned as chemical plants.

The development of chlorinated copperas was probably the pilot that started the present avalanche of chemical studies on sewage, but, on the whole, all of the modern methods are strikingly similar to the older ones in all respects except the method of concentrating and removing sludge, and in the methods of chemical control.

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Therefore a review of some of the older methods has more than a passing interest.

Sanitary engineers of former days recognized four distinct phases of the problem: (1) screening the sewage to remove garbage and coarse floating matter; (2) sedimentation with the aid of chemicals; (3) sludge disposal; and (4) treatment of the effluent from settling tanks.

According to the requirements of that time, a chemical, to be satisfactory for sewage treatment must "disinfect, deodorize, and cause precipitation of the organic substances contained in sewage. The conditions which are essential to success in this portion of the process, are to employ chemicals which are disinfectants as well as precipitants, which are readily obtainable in large quantities and at moderate prices, and which can be used in solution so as to add the least possible solid matter to the sludge." (Robinson and Mellis, 1877.)

The amount of sludge produced varied with the nature of the sewage and the chemical used. Birmingham produced 300 to 400 tons of sludge daily from 12,000,000 Imperial gallons of sewage, while Coventry produced 25 tons from 2,000,000 gallons.

Sludge was reduced to minimum bulk by sedimentation and decantation, and removed. Several methods of sludge disposal were tried prior to 1880: (1) as a dry powdered material to be used as fertilizer; (2) semi-dry for land dressing like barnyard manure; (3) enriched in fertilizing value by the addition of phosphates, ammonia, or other fertilizer materials; (4) burning into cement, when the lime content was high (General Scott's Process); (5) converted into fuel by mixing with other organic materials; and (6) used for the production of illuminating gas.

An attempt was made to produce cement from sludge at Birmingham and at Burnley in Lancashire by the Scott Sewage Company. Experiments were made in converting sludge into fuel and into gas at Coventry. Odors were objectionable and caused the abandonment of the process. The fuel value of the gas was high but its illuminating value poor, and at that time it was illuminating power that was wanted. The effluents were treated by sand filtration when secondary treatment was thought to be necessary. In many cases, the effluent was filtered through agricultural land to save the fertilizer matter it contained.

Precipitation plants were constructed and operated along one of three main types. (I) Processes using alumina as the principal coagulant. (II) Processes employing lime as the principal coagulant, and (III) Processes using iron salts.

Processes Using Alum

The Coventry Process was based on patents taken out in 1869 by the General Sewage and Manure Company, Limited. They contracted with

the Local Board of Health of Nuneaton and the Corporation of Coventry for the treatment of their sewage. Both contracts were based on the assumption that manure could be manufactured out of sewage solids and would be remunerative without subsidy from the community. The company spent considerable money in acquiring patents, erecting plants for the treatment of sewage, and in experimenting. Their annual losses finally proved fatal to them.

The sewage flowed by gravity to the plant of about 2,000,000 Imp. gallons daily capacity. It passed through screens (Latham's extractors) where the coarse material was removed. A dose of aluminum sulphate was added, which was prepared by treating shale with sulphuric acid. The sewage then received a dose of lime and flowed to four settling tanks. The effluent left the tanks in a fair state of purity and was dosed on nine acres of filter beds, used alternately. The effluent from the filter beds entered the river. About 25 tons of sludge were removed daily at 85 per cent moisture. Tanks were cut out of service and cleaned periodically. The sludge was filtered to about 65 per cent moisture by passing through a drum filter. Next it passed through a dryer (Millburn's drying machine) and was exposed to a low heating process. The moisture dropped to 60 per cent and the hot sludge was removed and stacked in piles. Moisture was further removed by evaporation until the final sludge contained 10 to 15 per cent water, in which condition it was sold either as removed, or after enrichment with chemical fertilizers. The plant used 2 tons of crude aluminum sulphate produced at the plant and about 1,000 pounds of lime for 2,000,000 gallons of sewage.

The A B C or Native Guano Process was patented in 1868 by Siller and Wigner. It consisted essentially in the use of alum, blood and clay. It was used in more or less the same form at Leicester, Leamington, Crossness, Tottenham, Bolton, Southampton and Leeds. A million gallons of sewage yielded 5¼ tons of sludge exclusive of precipitating chemicals and 12⅓ tons including chemicals. The coagulant analyzed about as follows:

Alum	600 parts
Blood	1
Clay	1900
Magnesia	5
Manganate of Potash	10
Burnt Clay	25
Sodium Chloride	10
Animal Charcoal	15
Vegetable Charcoal	20
Magnesium Limestone	2

Four pounds of this mixture was used for each 1000 gallons of sewage. The sludge was treated with sulphuric acid and dried into fertilizer. The composition of coagulant seems to have been varied from place to place and time to time, but the alum, blood and clay were always present.

The Phosphate Process, patented in 1870 by Forbes and Price, used phosphate of alumina and lime, for the purpose of producing a sludge of high fertilizer value.

The phosphate of alumina was mixed with sulphuric acid to make it soluble, after which it was added to the sewage, together with a quantity of lime to cause precipitation.

The process was tried at Barking and Hertford, but the results were not financially successful and the process was dropped. The main objections were that some phosphates were washed away in the effluent and that the sludge contained phosphate in a more insoluble and therefore less desirable form.

Bird's Process was used for some time at Stroud, Gloucestershire. It consisted in using what was called "sulphated clay." This was a mixture of clay and sulphuric acid in the proportions of 4 to 9 per cent of the former to 1 per cent of the latter. The sewage was weak and the effluent poor. The process was dropped.

Strothert's Process was patented in 1852, and employed alum, lime, zinc sulphate, and charcoal. To each gallon of sewage was added the following:

Alum	73.5 Grains
Zinc sulphate	3.5
Fine charcoal	73.5
Slaked lime	22.0

The process was unsuccessful and the results not much different from lime precipitation.

Processes Using Lime as the Chief Coagulant

Hilles' Process was patented in 1870. The precipitants were tar, lime, magnesium salts or similar chemicals, and the products arising from the calcination of lime. The patentee began his claims with the following sensible statement. "I do not propose to manufacture from sewage, water fit for drinking purposes, or a highly valuable manure. But I do profess to produce by my process an effluent water, at a reasonable cost, which is good enough, for all practical and sanitary purposes to be discharged into any river, and a sewage deposit which is perfectly harmless and inoffensive."

The process was installed in Edmonton, Middlesex, (800,000 gallons),

Tottenham (1,200,000 gallons), Grantham, Taunton, and Wimbeldon, Surrey. Chemicals were added in the form of a thick liquid in the proportion of 3 tons 7 cwt. per million gallons sewage.

Marsden's and Collins' Process employed lime, domestic ashes, ferric chloride, soda, and carbon (a by-product of prussiate of potash manufacture).

It was used at Bolton, Lancashire, on a sewage flow of about 2,500,000 gallons per day. The effluent was not filtered and was not particularly good. The sludge contained 85 per cent water and was disposed of to farmers for soil dressing.

Holden's Process was tried at Bradford in 1868 on about 130,000 gallons daily. Lime, coal dust or clay, and iron sulphate (probably ferrous) were used. Investigators claimed that a part of the putrescible organic matter was made soluble by the process and that the effluent was really worse than the influent. The sludge was valueless. The Rivers Pollution Commission also objected to the great increase in permanent hardness of the effluent by the excess lime in solution.

Blythe's Process, patented in 1858, used calcium superphosphate with magnesia and lime. It was the most costly of the chemical plants proposed and was never developed. The results were said to be unsatisfactory.

Fulde's Process, patented in 1875, used principally lime and sodium sulphate. The process was never fully developed because the effluent was unsatisfactory.

Whitthread's Process, patented in 1872, used a mixture of calcium phosphates (dicalcic and monocalcic) with a little lime. This process also had the object of returning all of the phosphates to the sludge as fertilizer. It was tried at Romford and at Luten, Bedfordshire, but was not accepted by the local authorities. It was also tried at Enfield, where it was said to be an improvement over lime, but too expensive, and was, therefore, not continued. In 1874 a company was formed, called the River's Protection and Manure Company, Ltd., for the purpose of treating the sewage of Tottenham. About 1,200,000 gallons were treated daily. Two pounds of dry chemicals were added to each 1000 gallons of sewage. The sludge was dewatered partly in tanks and further in Millburn's dryer, then bagged and sold. About 32 tons were produced per week. Reports regarding the effluent conflict,—some claiming it to be satisfactory and others that it contained too much of the original phosphates. The company finally ceased operation, the plant reverted to the Local Board, and a new process was adopted.

Campbell's Process, patented in 1872, employed soluble phosphate of lime. This was added to the sewage and later precipitated by the addition of lime. It was tried out at Tottenham on 3,500,000 gallons

of sewage per day. Later the process was tried out in a 5000-gallon pilot plant. Ten pounds of superphosphate of lime and 3 pounds of lime were used with each 1000 gallons of sewage.

Hanson's Process, patented in 1875, used lime, black ash, and red hematite treated with sulphuric acid. The black ash used was a by-product of soda manufacture and consisted largely of the sulphides of calcium and sodium. The process was tried at Leeds, but was discontinued for the use of lime alone.

Goodall's Process, patented about 1877, used lime, animal charcoal, ashes, and an iron liquid called sesqui-persulphate of iron. A company called "The Leeds Clarifying and Utilization of Sewage Company" was formed to operate this process.

Lime Processes. The first attempts to increase the sedimentation of sewage solids was by the addition of lime alone. The first patent was taken out about 1800 by Estienne for the use of lime in treating sewage. In 1841, Dr. Clark obtained a patent for softening and purifying water with lime. In 1846, William Higgs received a patent for the use of hydrate of lime in treating sewage.

In 1851, Wicksteed obtained a patent for the use of milk of lime in sewage treatment and the production of fertilizer from the sludge. These processes were placed in operation at Tottenham and Leicester. The products were known as "Tottenham Sewage Guano" and "Leicester Bricks." The projects failed as commercial enterprises, and were abandoned. In 1858, the Rivers Pollution Commission reported favorably on the lime process, but in 1867, the same commission condemned the process. At least thirty plants of this type were in operation, but all were gradually abandoned. About a ton of lime was used per million gallons of sewage. Plants of this type were erected at Blackburn, Birmingham, Bromley, Bradford, Chester, Leicester, Luton, and Ormesby.

The River Commission speaking of Luton said, "The sewage is clarified by a liming process. The effluent water, more or less clarified, flows direct into the stream of the Lee. This process of clarifying sewage improves it in so far as the solids are removed, but the fluid remains sewage, and if allowed to stagnate, will become putrid and offensive."

Captain Flower said, "These works being of a temporary nature, cannot be called satisfactory. . . . Although clarified, however, it is not purified sufficiently to be passed into a river of small volume from which drinking water is drawn. The sludge at Luton is said to be 'like all lime deposits, very filthy.' "

Birmingham produced nearly 400 tons of sludge daily, which was pumped from the tanks through long channels, allowed to dry, and then buried. The Birmingham Corporation held 258 acres of land for the

treatment of 12,000,000 gallons of sewage. Thirteen tons of lime were used daily.

It thus seems that lime treatment was in no case a success from either an economic or sanitary standpoint. The process was held to be expensive, did not produce the desired effluent, and produced a large quantity of sludge that was difficult to handle.

The following places tried to use the lime process but abandoned it prior to 1877: Banbury, Coventry, Cheltenham, Halifax, Hertford, Leeds, Southborough, Tottenham, and Worksop.

Processes Using Soluble Salts of Iron

Soluble salts of iron were used as early as 1660 to disinfect night-soil and foul conditions, but the cost was always too high.

At Northampton, chloride of iron was used with lime at the rate of 6 gallons of chloride of iron and 12 bushels of lime per million gallons sewage. The effluent was *filtered upward* through a layer of calcined iron ore 8 inches thick. In 1870 the system was abandoned under order from the Court of Chancery.

Other experiments were tried at Clyton using iron sulphate and lime, and at Cheltenham using iron perchloride. All were unsatisfactory.

Ferozone and *Polarite Process.* This process came along about 1890. The precipitant "Ferozone" was added and the effluent filtered through a filter containing "Polarite." An analysis of "Ferozone" was as follows:

Ferrous Sulphate	26.64	per cent
Aluminum Sulphate	2.19	
Calcium Sulphate	3.30	
Magnesium Sulphate	5.17	
Silica	11.35	
Magnetic Oxide of Iron	19.01	
Moisture	24.14	

The filter material "Polarite" analyzed as follows:

Magnetic Oxide of Iron	53.85	per cent
Alumina	5.68	
Magnesia	7.55	
Silica	25.50	
Lime	2.01	
Water (also trace of carbon)	5.41	

The "Polarite" was claimed to act as a carrier of oxygen. This process was used at Wimbledon. The "Ferozone" was ground in a mortar mill and added to the sewage in a semi-fluid condition at the rate of half a ton per million gallons of sewage. The effluent did not appear good because of the finely divided precipitate that passed out of the settling tank in the effluent.

Alumino-Ferric consisted of crude alum with a trace of iron salts. It came a little later than those previously listed, was used quite extensively and is still in use. It was added in doses of from 2 to 17 grains per gallon, depending on the strength of sewage. In many cases, it was used in conjunction with lime, with Ferozone, or even with the A. B. C. process.

This coagulant was used at Radcliffe (800,000 gallons), Heywood (630,000), Hendon (950,000), Chorley (900,000), York (with lime—3,500,000), and Willesden (with lime—1,940,000) besides many smaller installations.

Miscellaneous

Many other experiments were conducted and reported as not being satisfactory, such as Higg's, Dale's, and Dimsdale's at Croyden and Lenk's at Tottenham.

The Amines Process was tried at Wimbledon. From 30 to 50 grains of lime and 3 grains of herring brine per gallon were used. The clarification was said to be rapid and complete, and the sludge inodorous and non-putrescent. Sludge contained about 85 per cent water.

Electrical Precipitation was first tried about 1888 at Crossness by Webster. A modification has recently been tried out by the Niersverband. The electrodes are of iron which goes into solution at the anode, and then forms the hydroxide, which flocculates the sewage solids. Somewhat similar processes are found in that of Dr. Polatshick and that of Landreth.

Summary

The experience gained by all these former investigators is that the best coagulation is produced by iron salts and lime. Ferric salts in almost all cases were reported to be best. This fact was reported by Allan Hazen in 1889; in the Report of the State Board of Health, Mass., 1890, and by many others.

An examination of this array of experimentation, investigation, and exploitation covering the period from 1762 to the present is convincing enough that it is wise to proceed cautiously, and not to throw aside all concern for biological or other methods of treatment. The ultimate process developed will probably take into consideration both types of treatment. The remarkable thing is that there have been developed very few really new and unique ideas on the subject.

Acknowledgment

The following publications have been read with interest and very freely quoted, complete credit for which is here fully acknowledged.

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(3) W. Santo Crimp. "Sewage Disposal Works." 1890.
(4) George Waring. "Modern Methods of Sewage Disposal." (1876), (1885), (1903).
(5) Robinson and Melliss. "The Purification of Water-Carried Sewage." 1877.
(6) Sewage Disposal Appendices, Royal Commission. 1902.
(7) Various Reports of the Royal Commission.
(8) Staley, Cady and Pierson. 1891.
(9) U. S. Department of State (Report). 1899.
(10) R. Stracy. 1884.
(11) George Wilson. 1892.

Editorial

ACTIVATED SLUDGE RESEARCH

Important research studies on theories of sewage treatment are presented in this issue. The papers by Rudolfs and Trubnick on activated carbon, and by Kessler and Nichols on oxygen utilization by activated sludge, deal with fundamental phenomena associated with various phases of sewage treatment.

The property of adsorption that is characteristic of activated carbon was studied by Rudolfs by noting the removal from sewage of carbon dioxide or organic acids by addition of activated carbon. An analogy might be drawn between this adsorptive action and the phenomenon of clarification, either by absorption or adsorption, in activated sludge treatment. Study of such an analogy would serve as a complement to the work of Kessler and Nichols on oxygen utilization, to arrive at a theory that might, in part at least, help to explain the mechanism of activated sludge action. Neither adsorption nor oxygen consumption, alone, is sufficient to encompass a complete theory for the action of activated sludge. For that matter, a complete theory is bound to be quite complex, including as it must the relations of surfaces, bacteria, protozoa, oxygen content, temperature and time, but in the statement of any theory, at least a distinction must be drawn between the functions of solids (dissolved, colloidal and settleable), and relations of oxygen and oxygen demand. Studies of oxygen and oxygen demand enlighten us mainly as to the factor of environment—that is, we must provide the necessary conditions, as measured by oxygen content, for operation and maintenance of the active floc, which actually does the work of clarification by absorption and adsorption. Oxygen is of course depleted during the process of restoring the activity of the sludge floc, but the oxidation of floc surfaces is generally considered to be fundamentally biological and not due directly to chemical oxidation of organic matter. Therefore, studies of oxygen demand and dissolved oxygen concentrations in aeration tanks ought to be correlated with studies of adsorptive properties of the sludge floc, to give an expression of sludge activity.

This latter problem is probably more difficult, from the standpoint of research, than study of the problem of oxygen relations. Kessler and Nichols have reported an admirable study of oxygen relations and with further attention to solids concentrations, effective surfaces and adsorptive power (activity) we may arrive at a more scientific basis for control

of activated sludge aeration. The more difficult research remains to be done. Theriault (THIS JOURNAL, May, 1935, p. 377) has summarized the available literature dealing with the mechanism of activated sludge action. One of the most important references in his list is that referring to the work of Parsons in 1927 on the adsorptive properties of activated sludge. Parsons concluded that clarification was similar to adsorption and would follow the Freundlich adsorption isotherm.

This work was a good start toward fruitful research on the surface properties of activated sludge floc, but very little of value has been built on Parson's observations. It would have been of interest if the work had been continued by the British Water pollution Board, whose research started so bravely some years back at London University.

Valuable data might issue from a thorough study of the surface properties of the activated sludge floc, with development of some type of adsorption test that would show the degree of activity of activated sludge with respect to a given sewage. In the interest of standardization it would be desirable to use some specific salt or solute as adsorbate, such as ammonium salts, amines or carbohydrates. More work should also be done on the effect of mixtures of sewage, as is or treated if necessary, and activated sludge, considered from the standpoint of adsorption.

Occasional attempts that have been made to tackle this problem have yielded such conflicting results that the outlook has been somewhat discouraging. Nevertheless, the problem deserves long-continued and comprehensive investigation, inasmuch as a reliable and informative test to show the activity of activated sludge, related either to weight or surface, with respect to the sewage under treatment, would be of very practical value. Possibly some investigator may have an adsorptive index named after him, similar to Mr. Nordell's investiture with a "number."

F. W. M.

Reviews and Abstracts

ACTIVATED SLUDGE TREATMENT AT MANCHESTER, ENGLAND

Review of papers presented at the Summer Conference of the Institute of Sewage Purification at Manchester and abstracted with discussion in *The Surveyor* **88**, 43–45, 79–80, 91–92 (July 12, 19, 26, 1935).

Davyhulme Works Extensions.—The extensions to the Davyhulme plant at Manchester (see abstract, THIS JOURNAL, **7**, 765–66, July, 1935), consisting of large scale units for diffused air, Simplex surface aeration and Haworth bioaeration were described by Mr. C. G. Kent, resident engineer during construction. Aside from structural and construction matters the author stated that in the Haworth unit provision for the depth of flows in the channels had been decreased from 5 feet and the area increased in order to give the required capacity, in conformity with the conclusions of the late Mr. Haworth that the maximum depth should not be in excess of 3.5 ft. Another interesting observation was that in the 9-inch force main used for transporting about three miles the sludge with a water content of 88 per cent, the loss of head was almost exactly equal to that had water been pumped.

The discussion clarified several points concerning design features. Eight storm water tanks provide for 1½ hours detention only. If these were found to be inadequate additional capacity would be provided. Eight additional tanks are available for preliminary sedimentation, five ahead of the contact beds and three preceding the activated sludge process. All these 16 tanks are about 300 by 100 ft. in plan and vary in depth from 8.5 to 4.5 ft. The detritus is removed from the tanks by a travelling grab crane discharging directly into a tip wagon of 80 cu. ft. capacity or three times that of the grab. A centering device insured proper location over the wagon at the time of emptying. It was conceded that the ordinary type of centrifugal pump is satisfactory for pumping activated sludge but that the special type provided was an insurance against extraneous material that might be encountered. The question was raised as to the possibly lowered efficiency of the bioaeration unit as a result of the longer and deeper channels than generally considered advisable. It was stated that 220 acres of land were available for sludge disposal and that only half of this area was now in use. The sludge is broadcast and ploughed in.

Operation of the New Plant.—Operating procedures and a summary of the results obtained were given in a paper by Edward Ardern and

Clarence Jepson. The general procedure has been, in starting up the various units, to use a slow rate of flow of sedimentation tank effluent for the first week or two until the sludge was built up. In the later units surplus sludge was obtained from those in operation. Afterward the volume of sewage treated is dependent upon (1) the quality of effluent produced, (2) the degree of oxidation of the mixed liquor as it leaves the aeration tanks and (3) the biochemical and physical condition of the circulating sludge. The amount of sludge wasted is likewise dependent upon the sludge content in the aeration tanks. This surplus sludge from all the plants can be passed to a 200,000 gallon tank equipped with a Dorr picket-fence thickener either continuously or on the fill-and-draw principle. The supernatant water is returned to the inlet sewage channel for retreatment. The thickened sludge, or if the thickener is by-passed, the surplus sludge, is likewise returned, either to the inlet of the primary settling tanks or to storage. The sludge from these primary tanks is barged to sea, that from the storage tanks is pumped to land for final disposal. Provision is now being made for secondary digestion of this storage sludge prior to disposal on land. It is estimated that operating costs, including power but excluding renewals and cost of sludge disposal will be less than £1-12s. per million gallons treated.

Performance of Bio-Aeration Unit.—The plant, in continuous operation for 101 days, has treated 676,500 gallons average of settled sewage per day, corresponding to a detention period of 16.3 hours and using 40.7 b.h.p. per million gallons. A depth of 3.5 ft. of sewage is maintained in the channels. The effluent has been clear and except in two cases non-putrescible, although not meeting the Royal Commission standard for B.O.D. Best results were obtained when the proportion of sludge was held at between 5 and 8 per cent.

Simplex Aeration Plant.—After increasing the depth of immersion of the lip of the impellers, thereby providing better aeration, improved results were obtained but at the expense of additional power. The proportion of sludge in the aeration chamber when held at from 9 to 12 per cent gave optimum purification. The detention period was 14.6 hours during 52 days when 1,096,000 gallons per day were treated. Power required was 26.9 b.h.p. per million gallons.

Diffused Air Plant.—The first eleven weeks these five units were in operation a total of 871.5 million gallons of sewage was treated, employing a detention period of 12.7 hours, 0.887 cu. ft. of free air per gallon and 30.55 b.h.p. per million gallons. At the end of this period certain changes were made in air supply and rate of sewage flow. During the next 52 days 688.1 million gallons were treated with a detention period of 12.1 hours, using 1.20 cu. ft. of air per gallon and 36.95 b.h.p. per million gallons.

Independent Aeration Units.—These two units, of the same size as the other diffused air tanks, are operated for experimental purposes. A study of the optimum proportion of sludge in the mixed liquor has been undertaken. To date 5, 10, and 15 per cent of sludge, after one hour settlement, have been tried. So far there appears to be little difference whether 10 or 15 per cent of sludge is carried.

Some of the comparative results are presented in the following table, analytical results being in p.p.m.

1. 4-Hour Oxygen Absorption at 26.7° C.

Unit	Raw Sewage	Settled Sewage	Effluent	% Purif. Settled Sew.	
Bio-aeration	118.6	82.5	27.4	66.8	
Simplex Aeration	120.6	83.3	20.7	75.2	
Diffused Air, Main	117.9	85.3	26.7	68.7	Low air supply
" " "	120.6	83.3	22.1	73.5	High " "
Experimental Diffused Air					
(*a*) 5% Sludge	118.8	81.5	27.8	65.9	
(*b*) 10% Sludge	118.8	81.5	26.1	68.0	
(*c*) 10% Sludge	131.4	92.2	20.6	77.7	
(*d*) 15% Sludge	131.4	92.2	21.4	76.8	

2. Albuminoid Nitrogen.

Bio-aeration	8.4	5.5	2.1	61.8	
Simplex Aeration	9.3	6.45	1.55	76.0	
Diffused Air Main Plant	7.4	4.65	1.75	62.3	Low air supply
" " " "	9.3	6.45	1.7	73.6	High " "
Experimental Diffused Air					
(*a*) 5% Sludge	8.2	5.05	2.15	57.4	
(*b*) 10% Sludge	8.2	5.05	1.95	61.4	
(*c*) 10% Sludge	11.25	7.55	1.8	76.2	
(*d*) 15% Sludge	11.25	7.55	1.85	75.5	

3. Biochemical Oxygen Demand.

Bio-aeration	221.8	164.2	24.6	84.9	
Simplex Aeration	238.3	179.0	11.5	93.6	
Diffused Air Main Plant	208.7	152.9	16.6	89.2	Low air supply
" " " "	238.3	179.0	13.5	92.5	High " "
Experimental Diffused Air					
(*a*) 5% Sludge	211.6	157.2	22.3	85.8	
(*b*) 10% Sludge	211.6	157.2	18.0	88.6	
(*c*) 10% Sludge	236.5	178.8	10.3	94.2	
(*d*) 15% Sludge	236.5	178.8	9.6	94.6	

During these tests the authors point out that rainfall was below the average and the sewage consequently contained a high proportion of trade waste mostly from the dye-stuff industry. Periodic doses of greasy and oily matter also were received at the plant and interfered with effective aeration.

Discussion

Dr. Ardern in presenting the paper stated that of the three tests selected, he attached greatest importance to the reduction in B.O.D. He also advocated the consideration of overall or yearly averages for effluents rather than day to day results, which at times would not be up to standard, especially where excessive amounts of trade waste had to be dealt with.

Captain W. E. Speight (Bolton) inquired as to what, if any, advantage was to be obtained from densifying the sludge that was returned to the aeration tanks, to which the reply was made that only the portion of sludge disposed of on land was so treated. It was also brought out that the dissolved oxygen content of the sewage-sludge mixture in the aeration tank was determined upon the supernatant after rapid settling and not by the method proposed by Theriault and McNamee.

Mr. J. H. Edmondson (Sheffield) suggested that the aeration efficiency of the Haworth process was greatly affected by the design of the paddles and that progress was being made on this feature following the collaboration of Mr. Haworth on the design of this particular unit seven years ago. Dr. Ardern replied that this design had been left in Mr. Haworth's hands and that better results probably would be obtained if the depth of flow were reduced.

Mr. H. C. Whitehead (Birmingham) pointed out the advantages of ample preliminary sedimentation in reducing the work of the oxidation process. At Davyhulme, with 10 hours sedimentation, 30 per cent oxidation was obtained and at Birmingham 55 per cent. As regards reactivation of sludge he stated that his experience showed that reactivation was most beneficial with sludge containing 30 per cent solids after one hour settling. Stronger sludges generally gave little or no improvement. Dr. Ardern replied that the Davyhulme plants had not been operating long enough to demonstrate the benefits of reactivation.

Mr. F. R. O'Shaughnessy (Birmingham) discussed the difficulty of interpreting B.O.D. results of sewage effluents approaching the nitrification stage. (See This Journal, **5**, 931, November, 1933.)

J. K. Hoskins

DIGESTION OF ACTIVATED SLUDGE

By Edward Ardern and William T. Lockett

Paper presented at the Annual Summer Conference of the Institute of Sewage Purification at Manchester, England, July 12, 1935, and abstracted, together with discussion in *The Surveyor*, **88**, 89–90, 121–23 (July 26 and August 2, 1935).

Studies of sludge digestion were conducted at Manchester with the primary objective of determining the minimum digestion period required for the satisfactory maintenance of the fermentation process and resulting in a digested sludge suitable for land disposal without odor nuisance. Mesophilic digestion at 25 to 30° C. and thermophilic digestion at 50 to 55° C. were compared.

Description of Plant.—The experimental plant consisted of an open, concrete tank 6.25 by 4.5 by 5.0 ft. deep for pre-heating and feeding the fresh sludge to the two digestion tanks, each of 3220 gallons capacity and provided with hot-water circulation, thermostatic controls, temperature records, gas collection and gas meters. These tanks, square in plan and 15.5 ft. deep, were of concrete, had inverted pyramidal bottoms and were insulated. Piping permitted the circulation of top liquor or digested sludge in and out of the tanks. The additions or changes for the activated sludge experiments included means for: (1) concentrating the fresh sludge, (2) settling the liquor drawn from the digestion tanks, (3) settlement and further digestion of the digested sludge, and (4) circulation of the sludge in the tanks at various depths. Twenty covered drainage beds each 16 by 6 ft. in area were also provided.

Plan of Experiments.—Digestion tests at the two temperatures were carried out using: (1) activated sludge alone, (2) activated sludge plus about 10 per cent by volume of primary tank sludge and (3) activated sludge plus 15 per cent of primary tank sludge. Measured volumes of digested sludge were withdrawn each working day and replaced by similar volumes of fresh material, at the required temperature, which had been mixed with a suitable quantity of digested sludge. Samples of the withdrawn and added sludge were analysed, a daily record was kept of the volume of gas generated, the composition of the gas determined from time to time and data collected concerning the character of the digesting sludge.

Results.—Observations on each of the three above types of digesting material at the two temperatures are clearly stated and definite conclusions drawn from each set of results obtained.

It was determined that activated sludge alone, containing 98 per cent of water, digested at 25 to 30° C. for 10 or 11 days could be reduced to 60 per cent of its original volume and by second stage digestion for from 10 to 20 days it could be reduced to 20 per cent. Digestion at

50 to 55° C. for 5 or 6 days reduced such sludge volume to 30 per cent, while further settlement for some days at atmospheric temperature would contract the volume from 14 to 17 per cent of the original.

When 10 per cent of primary tank sludge was added to activated sludge and the mixture was digested at 25 to 30° C. and then at atmospheric temperature as above, the volume was reduced 67 per cent, whereas at 50 to 55° C. digestion temperature the volume was reduced 71 per cent, the gas yield was much higher and digested much more rapid.

In the experiments employing a mixture of 15 per cent primary tank sludge and 85 per cent by volume activated sludge, mesophilic digestion followed by second stage digestion reduced the bulk by 61 per cent. Thermophilic digestion followed by settlement only reduced the volume by 69 per cent. Drainability of these two sludges was satisfactory.

Principal Conclusions.—The principal findings of this study are summarized as follows:

"(1) That the digestion of activated sludge alone either at 25–30° C. or 50–55° C. is unattractive, mainly on account of the low gas yields, but also, in the case of digestion at 25–30° C., by reason of the difficulty of maintaining the optimum pH of the digesting sludge.

"(2) That the addition of 10 per cent (by volume) of tank sludge to activated sludge improves matters very considerably by increasing the gas yields two-fold, but in the case of digestion at 25–30° C., complete stability of the reaction of the digesting mass cannot always be ensured.

"(3) That if the proportion of tank sludge be increased to 15 per cent (by volume) the mesophilic and/or thermophilic digestion of activated sludge presents no difficulty, the gas yields show a three-fold increase, and a satisfactory pH of the digestion sludge is ensured.

"(4) That owing to the short period of digestion when treating the above mixtures it is not always practicable to remove directly any sensible proportion of water from the heated tanks, and therefore further treatment is required for separation of water and reduction in the bulk of sludge to be finally dealt with. In the case of mesophilic digestion, ten to twenty days' further detention in tanks at atmospheric temperature is sufficient to effect a good separation of water; the amount of additional digestion of sludge is not very material, but there is a definite lowering of the D.O.M. (organic and volatile) content of the sludge. Separation of water from sludge digested at 50–50° C. is more readily effected, five days' settlement generally being quite sufficient.

"(5) That the digestion of activated sludge, whether alone, mixed with 10 per cent of tank sludge or mixed with 15 per cent of tank sludge, can be effected at 50–55° C., in approximately one-half the time required for digestion at 25–30° C.

"(6) That the digestion of activated sludge either at 25–30° C. or at

50–55° C. is rendered a practicable project by a judicious preliminary admixture with tank sludge."

Discussion.—This interesting paper evoked much valuable discussion. Mr. F. R. O'Shaughnessy (Birmingham) questioned the necessity of preheating the charge of sludge before adding it to the digestion tank. Experience at Birmingham indicated that cold tank sludge put directly into a fairly large volume of warm digesting sludge caused no trouble. He was also rather skeptical of the short digestion period, 10 to 12 days in the digester and secondary digestion of about 21 days or a total of a little over 30 days. He also raised the question of the suitability of this digested sludge for land disposal. Anaerobically digested sludge at Birmingham was not assimilated by the land they had found after many years of trial and land disposal of such material accordingly had been abandoned. He pointed out also that gas production should be considered of secondary consideration rather than the primary objective of sludge digestion. This was also the concensus of several other discussors.

Mr. J. Bolton (Bury) remarked on the comparatively little increase in sludge from the activated sludge process over that of plain sedimentation. Although Ardern had stated this increase amounted to about 80 per cent, the speaker from his extended experience found this increase to be much less than that—about 25 per cent. He was also optimistic concerning the ability of the digestion process to produce sufficient gas to maintain thermophilic digestion temperature in the tank without additional fuel. He was certain too that there would be no odor nuisance from properly digested sludge.

Mr. H. Jackson (Gravesend) called attention to results similar to those in the paper, obtained from a large scale plant, indicating that the conclusions drawn were sound. Although he agreed that the production of gas was a secondary consideration, he questioned the shortness of the digestion period proposed (30 days). His experience showed that 35 days in the primary tank and 35 days in the secondary tank produced a satisfactory drainable sludge.

Mr. H. Lumb (Halifax) stated that similar experiments to those described were under way at his plant using activated sludge alone and mixed with its related humus sludge and that in general the results had been comparable to those of the authors. However, with thermophilic digestion the sludge had deteriorated rather than improved. Mr. H. Taylor confirmed this observation from experiments he had conducted at Sheffield.

In closing the discussion, Dr. Ardern acknowledged that the total digestion period was short but that it should be pointed out they were not aiming at complete digestion and that the results obtained justified the

conclusion. Proper concentration of sludge and of seeding conditions were essential requirements. Concerning the suitability of the product for land disposal, this was dependent upon the method of working. They had adopted the principle of using a large number of plots, applying small quantities of sludge on each, plowing the material in at once and repeating the process three or four times a year, rather than overdosing once each three or four years. Moreover, they did not consider the sludge as a fertilizer, but rather the land as a final disposal area without nuisance. Thus far the method had been successful from that viewpoint. The unfavorable results from thermophilic digestion mentioned, he suggested, might be due to the type of seeding employed.

J. K. HOSKINS

PRACTICAL ACTIVATED SLUDGE RESEARCH

BY J. N. H. KESSENER AND F. J. RIBBIUS

Paper presented at the Annual Summer Conference of the Institute of Sewage Purification held at Manchester, England, July, 1935 and abstracted, with discussion in *The Surveyor*, **88**, 59–60, 92–94 (July 19, 26, 1935).

This paper is a further exposition of the subject as discussed in a paper by the same authors published in THIS JOURNAL in May, 1934, and to which the reader is referred. The primary objective is to outline a practicable method for studying the effectiveness of the activated sludge process, in order that the individual plant may be designed to meet local conditions, or to "put the right activated sludge plant in the right place." Briefly the proposed procedure is based on the assumption that purification capacity is dependent mainly upon oxygenation capacity and that determination of these factors for a specific sewage can be accomplished by an experimental plant of wide flexibility operating simultaneously with an additional control plant treating the same sewage under one set of constant conditions.

The rationality of the scheme is based upon two postulates underlying purification by the activated sludge process which are stated to be:

1. Purification = (*a*) sludge production + (*b*) biochemical oxidation. (*b*) is essential to (*a*) and influences (*a*) in a manner and to a degree unknown.
2. The rate of biochemical oxidation is proportional to the rate of bacterial multiplication and is limited by:
   - (*a*) the supply of organic matter (B.O.D.) Phelps' law.
   - (*b*) the supply of oxygen
   - (*c*) the supply of N, P, K, etc.
   - (*b*) inhibitory effects of products of bacterial metabolism, of pH, of germicides, of temperature, etc.

Discussion

The subject matter of the paper was quite widely discussed and was generally acknowledged to be of an intricate technical nature, but one which represented a worthy effort to rationalize the process and produce a method of measuring the purification effected.

Mr. W. D. Scouller (Huddersfield) accepted the postulate that oxygen was absolutely essential to continued effective purification although this theory was not universally accepted. He cited experiments he had made to support his conviction on this point. He also pointed out that the Phelps' law applied only when an efficient amount of oxygen was present in the system and that this point must be taken into consideration in developing the procedure. He questioned the advisability of using water in the tank for determining the oxygenation capacity rather than sewage, because of the difference in oxygen absorption between water and sewage. The difference has been frequently observed although the cause is not as yet explained.

Dr. W. Watson (Burnley) stated that actual research, employing the full scale plant, was the only way to bring about working economies. Once oxygenation capacity of an aeration tank was determined that would hold constant wherever the tank was erected, a point of particular importance to the manufacturer. Also oxygenation performance, or the rate of oxygenation of tank contents under actual operating conditions, and which depended practically on the degree of saturation of the oxygen present rather than on the character of the sewage treated, could be determined for any particular type of plant at all possible degrees of oxygen saturation and other conditions of temperature, pressure, etc. and could be generally applied, regardless of the quantity of sewage treated. He questioned the advisability of using the B.O.D. test alone for calculation of the purification effected and cited examples from which misleading conclusions might be drawn if the results of the B.O.D. test only were considered.

Mr. J. H. Spencer (Northampton) supported the previously expressed view of Mr. Scouller that the authors had disregarded an important part of the Phelps' law, namely that the rate of biochemical oxidation was independent of the oxygen content of the sewage-sludge mixture in the aeration tank. He ascribed unsatisfactory results in many plants to the fact that towards the outlet end of the tanks no excess oxygen was maintained and hence the oxidation rate was retarded. He defined the minimum requirement to be such that sufficient oxygen be available for complete purification and just a little over to start nitrification after oxidation was complete. A weakness in the authors' scheme was that the experiments described required a full scale plant and when once con-

structed it could not be replaced with the permanent modified type indicated by the experimental results.

J. K. Hoskins

A STUDY OF THE GRIT CHAMBER OF THE WERDHÖLZLI TREATMENT PLANT, ZURICH

By Dr. O. Acklin

Gesundh.-Ing., 57, 666 (1934)

A satisfactory grit chamber removes as much mineral matter as possible and prevents sand from depositing in the settling tank. In general, the sewage should have an average uniform velocity of .2 to .35 meters per second. The minimum length should be so determined that the solids reach the floor and the maximum length depends upon the length of time between cleanings. The present shape of the grit chambers in Werdhölzli is unsatisfactory because a sudden transition is made from the relatively small cross section of the sewer to the larger one of the grit chamber. This results in average velocities of 30.6 cm. per second in one channel and 18.9 cm. per second in the other, at a rate of flow of 2280 liters per second. The eddy currents and the unequal distribution of sewage caused by this condition can be corrected by a suitable connection between the sewer and the grit chamber.

The grit chamber is operated so that, with an average flow of 2000 liters per second, the left or right channel is used alternately and during high flows the center channel is put into operation.

The removal of sand in the grit chamber was satisfactory as the sand content of the samples from the grit chamber varied between 37 and 46 per cent whereas that of the fresh solids in the first settling tank was only 10 to 15 per cent.

Particles greater than 4 mm. and less than .5 mm. in size made up a small part of the sand and the portion containing particles from .5 to 4 mm. in size made up more than half of the total. The grit was composed almost entirely of particles which settled rapidly and contained only a small amount of those which settled slowly. This is borne out by the fact that behind the grit chamber only a small amount of particles larger than 1 mm. were found and a sample taken from the effluent channel showed that 90 per cent of all the settleable solids had a size of less than .5 mm. in diameter. The minimum settling velocity of sand with a size of about .5 mm. is about the same as the maximum settling velocity of sewage particles which, according to Blunk, is about 5 cm. per second. In a grit chamber operating satisfactorily the size of most of the particles deposited should be more than .5 mm.

The results of experiments show that the sand not retained by the grit chamber consists of very small particles which have the same settling velocity as the sewage solids and that the grit chamber operates satisfactorily with a maximum dry weather flow of about 2000 liters per second.

E. Meyer-Peter has presented a formula showing the relation between the length of the grit chamber, velocity of flow of the sand particles and the settling velocity of the particles in moving water. With a velocity of flow of v_m meters per second, the length of the grit chamber is

$$L = H \frac{v_m}{w_m} \text{ meters}$$

where H is the depth of the water in centimeters and w_m the settling velocity of the particles in flowing water in centimeters per second. The minimum settling velocity w_m for sand particles 1 mm. in size is 8 centimeters per second, according to Blunk, and the average velocity of the water in the grit chamber has been determined as .3 meter per second. With an average depth of two meters

$$L = 200 \frac{0.3}{8} = \text{about } 7.5 \text{ meters.}$$

These values agree with those of the Werdhölzli grit chamber. For greater depths or larger flows the Werdhölzli grit chamber is too short.

The calculated values are evidently only valid if v_m and w_m remain constant over a long period and the experiments showed that this was not always the case at Werdhölzli.

During the first half of 1933 an average of two cubic meters of grit was obtained each day. The analyses of the grit are shown in the following table:

Number of Analysis	1	2	3
Dry Solids	44.5%	39.6%	48.3%
Loss on Ignition	31.0%	21.8%	27.3%
Fixed Solids	69.0%	78.2%	72.7%

The water content is high because the grit is removed mechanically without drawing down the tank and because of the large amount of sewage solids. That the organic matter in the grit is about three times as high as it should be is due to the low velocity of the water in the grit chamber.

G. P. EDWARDS

THE SLIDING PROPERTIES AND SETTLING VELOCITY OF FRESH SOLIDS AT THE WERDHÖLZLI TREATMENT PLANT, ZURICH

By Dr. O. Acklin

Gesundh.-Ing., 58, 52 (1935)

The peculiarity of the sewage solids obtained in the Werdhölzli plant is that those in Hopper I of the settling compartment do not slide into the sludge chamber without mechanical aid and the sludge piles up around the withdrawal pipe in this compartment, does not flow and usually the water breaks through. This phenomenon may be attributed to too flat a slope of the floor, to an increase of the adhesive qualities or internal friction of the fresh solids because of the presence of light oil, such as benzol and xylol, or to the texture of the solids.

The effect of the slope was studied by means of a sheet metal hopper, the floor of which sloped 60° from the horizontal. Sludge from each of the four hoppers was used and it was found that with this slope none of the sludges would slide through the opening. In another experiment a concrete plate 15 inches high was covered with sludge from the four hoppers. With a slope of 42° the sludge from Hoppers I and II slid down in 15 to 30 seconds with a velocity of 1.2 to 2.5 cm. per second. The sludge from Hopper III moved only slightly, whereas sludge from Hopper IV remained stationary with a slope of 42° but partially slid down in 20 to 30 seconds with a slope of 52°.

To determine the effect of light oils sludge was treated with xylol and tested on the concrete plate. No difference in sliding properties between the xylol-treated sludge and the control could be observed. The finely divided solids from Hoppers III and IV did not slide satisfactorily even with slopes of 60° to 75°.

It is evident from these experiments that the unsatisfactory sliding qualities of the fresh solids are not due to the slight slope of the floor or to the presence of light oil but to the peculiar texture and bulkiness of the sludge. It seems that the fresh sludge of Hopper I contains a large amount of coarse and bulky solids.

This unsatisfactory sliding can best be eliminated by the removal of the coarse, heavy solids in preliminary tanks. Experiments made to determine the minimum settling period for removing these solids showed that a detention period of three to four minutes was sufficient. Hopper I still has to handle about 20 per cent of this coarse sludge but it is believed that in this way the operating difficulties have been partially or completely overcome.

G. P. Edwards

DISCUSSION OF CLARIFICATION PLANTS

By Dr.-Ing. Mahr

Gesundh.-Ing., 57, 581 (1934)

A large city must build sewers for the removal of wastes but it does not have the right to pollute rivers. Suitable methods of sewage treatment are available to fit nearly all cases and the cost of sewage treatment is usually only a small fraction (about 10 per cent) of the cost of the sewer system. The gross pollution of rivers is not a necessary evil but a lack of consideration which cannot be condemned enough. Even when sewage treatment plants are provided the operation is often neglected. It is necessary to have proper design as well as suitable supervision during construction and operation.

Plants consisting of sedimentation tanks remove only the suspended solids and not the soluble substances. Screening plants are even less efficient. Even with the best operation, plants of these types may pollute rivers. Sometimes treatment plants do not handle all of the sewage and storm water is discharged directly into the river. Even the best sewage treatment plant cannot sufficiently protect a river if only part of the sewage reaches the plant or if it is very badly overloaded.

It is especially important to remove the sludge as a river is much more heavily polluted through solids which settle quickly than by an equal amount of soluble material which is distributed over long stretches. Before deciding upon biological treatment the construction of more settling tanks to treat storm water should be considered. Under some circumstances impounded streams may be used as settling tanks.

Supernatant liquors from separate sludge digestion tanks or the very turbid liquors obtained from washing settling tanks should not be discharged directly into a river but pumped back to the raw sewage entering the plant.

Important data, such as the amount of sewage and its distribution over the hours of the day and power requirements of the individual machines should be obtained by direct measurement.

A knowledge of the peculiarities of the sewage is, to a large extent, a matter of experience, which can only be gained through actual operation. A familiarity with other plants will aid in avoiding mistakes and unnecessary work.

G. P. Edwards

WASTES FROM FOOD INDUSTRIES

By Prof. Dr. Strell

Gesundh.-Ing., 57, 664 (1934)

A partial list of the food industries includes:

1. Meat packing
2. Fermentation, including malts and yeast
3. Milk, dairy and margarine
4. Starch flour
5. Kraut and vegetable canning

Meat Packing

In the meat packing industry the most important wastes consist of the contents of the stomach and the intestines and the blood. The pulpy and liquid wastes quickly become septic, resulting in acid fermentation, hydrogen sulphide formation and fungal growths. All solid and pulpy material may be placed in metal containers and the grease collected in suitable grease traps. Where dilution is adequate bar screens may be sufficient treatment but with less dilution, carefully controlled clarification plants or digestion pits may be required. Further clarification may be obtained by broad irrigation if sufficient garden or cultivated land is available. In Munich the solids from slaughter houses are ground up and discharged into the sewer. The practice of collecting fresh blood for the manufacture of blood meal is to be recommended.

Fermentation

Breweries.—The wastes are obtained from the discharge of the grain and hop residues, from the mash room and the brew house, from washing and cleaning the mash and brewing pans, from the filter and racking rooms, from the fermentation and storage cellars, from the cask and bottle washing and from the machine and refrigerating rooms. The waste, the composition of which varies greatly, contains, besides the solid grain and hop particles, soluble organic nitrogen compounds, yeast cells and sewage fungi. It becomes septic rather quickly and induces rapid fungi growths, which tend to form organic acids. Since ordinarily it is discharged with large quantities of pure water, usually this waste is not very objectionable. It can best be handled at a treatment plant with the domestic sewage as the introduction of brewery wastes into diluting water has always caused heavy growths of algae. The organic suspended solids should be removed by suitable screens or by settling tanks and the liquid may be purified by broad irrigation or on trickling

filters. Pure condenser water should be added after mechanical clarification. Chemical or electrical methods of purification have been found too expensive.

Malt and Diamalt.—Wastes from the malt and diamalt industry include the wash and steep water from the barley, waste grain, condenser water and wash water from the mash pans. The composition, properties and purification are, in general, similar to those of brewery wastes. In Munich the wastes from a diamalt factory undergo mechanical clarification, followed by biological purification in fourteen large digestion ponds and partial use of broad irrigation.

Distilleries.—Wastes from distilleries consist of the wash water from the potatoes, cooking vats, mash and fermenting vats and condensed steam. The potato wash water contains particles of potato, bacteria and sand. The condensed steam contains dextrin, sugar, solanine, resins and starch, which rapidly become septic and which encourage the growth of fungi. The solid organic matter may be removed by screens, the sand by sedimentation and the effluent treated either by broad irrigation or on intermittent sand filters. Sewage fish ponds have also been successfully used.

Yeast Factories.—The wastes from yeast factories, which include the slops and the wash water from the presses, wash tubs, acid troughs and yeast vats, are very difficult to treat. They contain inorganic salts and free sulphuric acid as well as yeast and colloidal organic solids which rapidly become septic and which settle very slowly. The waste becomes slightly acid from the press water but strongly acid from the slops. If sufficient diluting water is available, mechanical clarification and neutralization are sufficient. When possible, the acid wastes should be collected separately and the other wastes treated by sand filtration. Bach recommends that these wastes be treated in contact aerators.

Milk, Dairy and Margarine Industries

Fresh Milk Dairy Farms.—The wastes consist of the wash water from milk cans, apparatus and work rooms.

Dairies Producing Butter.—No wastes are discharged since the products are too valuable.

Dairies Producing Cheese.—The waste, which is small in volume, contains considerable amount of common salt, whey and particles of cheese.

In general, the most important constituent of dairy waste is milk, chemically a mixture of lactose, casein and fat in water. In addition to milk, the wastes from fresh milk and butter dairies contain soda from the purification of the cans and occasionally a disinfectant, such as chloride of lime. These wastes may be discharged directly into a stream if sufficient diluting water is available. If necessary, they may be

settled and treated by broad or sub-surface irrigation. The use of chlorine will retard fermentation and prevent odors. Poisonous disinfecting substances must be diluted with pure water so that there is no poisonous action in the diluting body. As much of the whey as possible should be removed from cheese factory wastes.

Starch Flour Industries

Starches are obtained from potatoes, corn, rice and grain. In the manufacture of potato starch, water is used in cleansing and for hydrolysis but in the production of starch from rice and grain, sodium hydroxide and acids are used to hydrolyze the raw material and to precipitate the gluten.

Potato Starch Manufacture.—The wash water from potatoes, which contains small particles of potato, bacteria, root fibres and straw, is relatively harmless but the wastes from grinding the potatoes are injurious because they contain substances which rapidly undergo acid fermentation and produce hydrogen sulphide. Other wastes consist of starch wash water and the liquor from the pulp presses. If sufficient land is available the entire waste may be purified by broad irrigation. With insufficient land the waste from grinding the potatoes should be treated by broad irrigation and the remainder clarified by screens or settling tanks and discharged into a river in as fresh condition as possible.

Potato Flake Manufacture.—The washed potatoes are cooked under pressure and the pulp is passed between heated cylinders to form a flat cake. The wastes which are obtained from washing the potatoes and cleaning the cooker may be purified by screening or settling. Broad irrigation may be used under some circumstances.

Rice, Corn and Cereal Starch Manufacture.—The wastes result from the doughing-in process (weakly acid waste), from the decomposition of raw materials with caustic soda (alkaline wash water) and from the precipitation of the gluten with sulphuric acid or hydrochloric acid (acid wash water). The acid and alkaline wastes should be combined and, if necessary, neutralized with lime. They may be purified by broad irrigation or, after clarification in settling tanks, discharged into suitable bodies of water.

Kraut and Vegetable Canning

Kraut.—The wastes resulting from the overflow of the fermentation vats and from draining the presses may be treated by broad irrigation, in leaching basins or by discharge in small streams into a diluting water.

Vegetable Canning Factories.—The wastes, which result from wash-

ing the fresh vegetables before grinding and preparing them, may be discharged into earthen basins or gravel pits. Solids, such as leaves, roots, may be composted.

The characteristic constituents of wastes from the manufacture of food products are carbohydrates (starch and sugar), fats, proteins and the decomposition products resulting from oxidation or reduction. In general, the wastes may be treated on land or discharged into rivers in the freshest condition possible. High cost prevents the frequent use of coagulants or chlorine. Artificial biological purification processes, such as trickling filters, contact beds and contact aerators should be used only in case of necessity.

G. P. EDWARDS

TREATMENT OF TRADE WASTE WITH ACTIVATED CARBON

BY FOSTER DEE SNELL

Ind. Eng. Chem., **27**, 825 (1935)

Waste liquor from a plant which dyes silk and silk-mixed goods consists of concentrated dye waste, acid waste, boil-off, caustic waste and dilute dye waste. The dilute dye waste, which amounts to about 150,000 gallons daily, is the fraction that is treated.

The waste is collected in a small averaging basin, which has a detention period of 1 to 2 hours. From the averaging basin the waste passes to a treating basin where it is mixed with activated carbon for a period of 5 minutes. The carbon is filtered off and the filtrate is discharged directly to the river. The amount of carbon used is 6 pounds per 1000 gallons. The carbon can be re-used several times before reactivation. The material cost is about 2 cents per 1000 gallons. This treatment, though it does not remove oxygen consuming materials, is very efficient in removing color.

P. D. MCNAMEE

ACTIVATED SLUDGE AS A BIO-ZEOLITE

BY EMERY J. THERIAULT

Ind. Eng. Chem., **27**, 683 (1935)

The active adsorptive agent of activated sludge was found to be chemically identical with the zeolite used for removing hardness from water. Prior to analysis, the activated sludge was aerated several days with the

addition of ammonia in order to oxidize most of the adsorbed material and to obtain an actively nitrifying sludge. Mineral analysis showed that the ash from this sludge contained 45.77% SiO_2, 24.96% Al_2O_3, 1.08% Fe_2O_3, 0.83% Mn_2O_3, 7.58% CaO, 2.54% MgO, 4.44% Na_2O, 2.96% K_2O, 0.30% SO_3, and 8.39% P_2O_5. A correction for bacterial ash was applied to the above values. In deriving this correction, it is assumed that nearly all of the phosphorous is concentrated in the bacterial cells. The other mineral constituents of bacterial cells are proportioned to the same scale as the phosphorous and deducted from the observed values. The corrected values correspond to a zeolite with the composition $0.84\ M_2O \cdot R_2O_3 \cdot 3SiO_2$. Activated sludge from an entirely different source was found to correspond to a zeolite with the empirical formula $R_2O_3 \cdot 4SiO_2$.

P. D. McNamee

SLUDGE INCINERATION AT DEARBORN

By Mark B. Owen

Water Works and Sewerage, **82**, 261 (August, 1935)

An incinerator to dispose of all sludge was installed at the sewage treatment plant of Dearborn, Michigan, early in 1935. The incinerator, a Nichols-Herreshof, is a circular multiple-hearth air-cooled unit of refractory materials enclosed in a steel shell. It contains a slowly revolving central shaft to which are attached rabble arms to convey the sludge across the hearths to the ports through which it drops from one hearth to the next. The shaft and rabble arms are air-cooled by forced draft from below. The teeth on the rabble arms clear the hearths by about three inches to allow an insulating ash blanket to accumulate. The cooling air from the rabble arms is passed through a recuperator, or preheater, where it is warmed by the exhaust gases from the incinerator and is then used to supply air to the oil burners and for combustion on the incinerator hearths. The exhaust gases from the recuperator are passed to the plant heating boilers.

The sludge cake from the Oliver vacuum filters is conveyed by a belt to the feed hopper on top of the incinerator, being automatically weighed en route. The sludge is admitted to the top or No. 1 hearth, where most of the moisture is driven off. Under normal loading, combustion starts on the second hearth and is completed by the time the sludge is part way across the fifth hearth. The sixth, or lowest hearth, acts as a cooling chamber for the ash, which then drops into a pit and is removed by a bucket elevator. Hearths 1, 2 and 4 are equipped with oil burners using

a No. 6 fuel oil. A 90-day acceptance test was made from February 25 to May 26, 1935, at the normal rate of sludge production and a 48-hour continuous test at the design rate of 50 tons of filter cake per day on March 8 and 9.

Tables of operating results are given, both on a 24-hour average and hour by hour records for two typical days. On one of these days (May 4) the furnace had already operated 88 hours without fuel oil. On this day the sludge feed averaged 3871 lbs. per hour. No fuel oil was used. The exhaust gas from the incinerator averaged 1234° F., and the exhaust gases from the recuperator averaged 1003° F. From noon April 30 to noon May 5, a total of 240.59 tons of sludge was incinerated without the use of any fuel oil. The sludge averages 65 per cent water. Solids average about 50 per cent combustibles of approximately 10,000 B.T.U. per pound. The cost of incineration, including amortization, depreciation and maintenance, has ranged from 57 to 74 cents per ton of sludge cake. The sludge burns to a very fine ash, which averages about 15 per cent by weight of the sludge cake and contains less than 1½ per cent of organic matter.

R. S. SMITH

CHICAGO STARTS WORK ON FOURTH LARGE SEWAGE PLANT

BY L. C. WHITTEMORE

Engineering News-Record, 115, 6, p. 186 (August 8, 1935)

Chicago's new southwest treatment plant, located just west of the existing West Side works, is designed as a 400 m.g.d. unit, with provision for extensions up to 1200 m.g.d. Contracts have been awarded for the construction of two sections of the interceptor, which completed will be 11 miles long with a maximum section 17 ft. × 19 ft. The plant, of the spiral flow activated sludge type, will consist of two batteries of eight, four-pass, aeration tanks, providing 1736 feet of travel 15 ft. deep by 34 ft. wide; 32 circular final settling tanks, 126 ft. in diameter with baffled central inlet and peripheral overflow weir, 11 ft. side depth with a 1:12 slope toward the center and a four arm rotating mechanism operating at 1 revolution per hour. Both sewage pump and air blowers are steam turbine-driven. The return sludge is lifted by air, then flows by gravity to the sewage inlet. Between each battery of aeration tanks and its corresponding settling tanks is an operating gallery. Venturi meters are used to measure the flows of sewage, air and return sludge. Incineration of excess sludge is planned.

The plant was designed on the following basis: 400 m.g.d. average to 600 m.g.d. maximum; 5 hours detention period in aeration tanks, 0.5 cu. ft. of air per gallon of sewage, 20–30 per cent return sludge, 2000 to 3200 p.p.m. suspended matter in the mixed liquor and 1200 to 1950 gallons of mixed liquor per square foot per day in the final settling tanks.

R. W. KEHR

CHEMICAL-MECHANICAL TREATMENT OF SEWAGE

BY P. B. STREANDER AND M. J. BLEW

Public Works, **66**, 7, pp. 17, 18 and 22 (July 25, 1935)

With mechanical equipment for handling the coagulants and sludge and recent improvements in coagulation control, chemical treatment of sewage provides an extremely flexible and controllable process. Chemical treatment concerns itself largely with removal of the colloidal portion of sewage solids and since these may carry either a positive or negative charge, depending largely upon the characteristics of the water supply, each sewage presents a separate problem. Proper coagulation requires that the electric charge be raised or reduced to the isoelectric point.

In 1889, Hazen, after a thorough study of various coagulants then in use, reported best results from the use of ferric sulfate, second best with copperas and lime and third best with lime alone. The ferric hydroxide floc may be obtained by adding ferric sulfate or chloride at proper pH to the sewage, by chlorinating copperas, or by blowing $\frac{1}{8}$–$\frac{1}{12}$ cu. ft. per gallon of finely divided air through sewage treated with copperas and lime, about 30 minutes being required to complete the reaction. Ferrous chloride, obtained by the action of chlorinated water upon scrap iron may also be oxidized in an alkaline state with compressed air, the dosage of chemicals in this case being regulated by the rate at which chlorine is fed.

R. W. KEHR

PERFORMANCE OF GENEVA'S SEWAGE TREATMENT PLANT

BY E. R. WELLS

Public Works, **66**, 7, 20–22 (July, 1935)

The sewage treatment plant for Geneva, Illinois, is designed for a 1950 population of 8500 with a per capita flow of 100 gallons per day.

The present contributing population is 5500 and the average 5-day B.O.D. of this purely domestic sewage is 340 p.p.m. The plant contains the following features: 1⅝" opening, manually-cleaned, bar screen; a 3 m.g.d. Venturi meter with by-pass for flows in excess of this amount; 1½ hours preliminary sedimentation in a hopper-bottom tank with 55° bottom slopes; by-pass of settled sewage flows in excess of 200 gallons/cap./day; nine aeration tanks with mechanical surface aerators providing 7½ hours detention with 25 per cent return sludge; mechanically cleaned, rectangular, final settling tank designed for 1,100 gallons/sq. ft./day with hydrostatic sludge discharge to sludge pumps; sludge division box, heated digestor with 2.5 cu. ft./capita capacity, equipped with cover and gas collection mechanism to provide for heating the buildings and digestor; and covered sludge drying beds of 0.45 sq. ft./cap. equipped with overhead monorail dump buckets which discharge directly into trucks. B.O.D. reduction has averaged 97 per cent. During 1934 the gas yield was 1.4 cf./cap./day.

R. W. KEHR

USING POWDERED ACTIVATED CARBON IN SEWAGE TREATMENT

ANONYMOUS

Public Works, **66**, 7, 12 (July, 1935)

Powdered activated carbon fed at a rate of 40–50 lbs. per m.g. from a dry feed machine with water ejector to the trunk sewer before it enters the plant results in increased gas production, decreased scum formation and odor control. The activated carbon may also be fed to the raw sludge pumps or to the digestor. Beneficial results are reported with 15 lbs. per m.g. at Fairport, New York, 40 lbs per m.g. during the winter months at Garden City, New York, 35 lbs. per m.g. at Newark, New York, and at East Rochester, New York. Other miscellaneous benefits noted at these plants included: high solids content of the sludge, better clarification of the supernatant liquor, a "dryer" digestor gas, 25 per cent less gas required to run a gas engine. No change was noticed at East Rochester in the removal of suspended matter.

R. W. KEHR

ELIMINATING ODORS AT SEWAGE TREATMENT PLANTS

ANONYMOUS

Public Works, **66**, 6, 41 (June, 1935)

This is an abstract of a paper by Harold Wilson, biochemist of Johannesburg, South Africa, delivered before the Royal Sanitary Institute. Sulphide odors may be eliminated by using lime to maintain the sewage in a slightly alkaline condition, or by the use of chlorine. Maximum absorption by the lime was obtained in one case by adding milk of lime to an outfall 1¼ miles above the plant, but this advantage is lost if the sewage is to be pumped. Screenings should be incinerated or disintegrated and the process housed. Minimum exposure to air in Dortmund type tanks is favored.

For deodorizing the air from sealed enclosures over odor-producing processes; activated carbon handled 40,000,000 cu. ft. of air per cu. yd. but was difficult to reactivate without producing odors; passing the air through the compressors into activated sludge was satisfactory but was not used due to possible detrimental effects upon the activated sludge; ozonization of the air was both cheap and effective and was finally adopted at Johannesburg.

R. W. KEHR

SEWERAGE PLANNED FOR A 1970 CITY AT CEDAR RAPIDS, IOWA

ANONYMOUS

Engineering News-Record, **115**, 4, 118–121 (July 25, 1935)

A recently constructed intercepting sewer was designed for the probable 1970 population, using existing zoning laws as a basis for estimating future growth for each drainage area. Infiltration was estimated from measurements on alternate wet and dry weeks in existing sewers at 70 gallons per capita per day. The design figure for total flow was 195 gallons per capita per day. The present good condition of a concrete sewer built in 1887 from Milwaukee natural cement resulted in the use of 36″ to 42″ circular precast concrete pipe for the new interceptor except for one section of concrete with a clay liner where rapid completion of the sewer was necessary while tunnelling. An 18″ length of the precast pipe was made up daily and subjected to a crushing test.

R. W. KEHR

NEW ACTIVATED SLUDGE PLANT AT TOYOHASHI, JAPAN

By Ichiro Honda

Journal of Suido Kyokai, 22, 80–84 (March, 1935)

A Simplex type activated sludge plant has recently been placed in operation at Toyohashi, which is located half-way between Tokio and Osaka on the Pacific coast of Japan. The plant is designed for an ultimate population of 86,500, contributing a maximum dry-weather sewage flow of 4.2 m.g.d., based on 45 gallons per capita per day. The plant occupies an area of 2.72 acres and the tributary area is about 1035 acres. During wet weather, the plant is capable of treating two times the maximum dry-weather flow.

The plant consists of a horse-shoe shaped intercepting sewer 8 ft. wide by 6.5 ft. high; three grit chambers; a pump house; two primary sedimentation tanks; twenty-four aeration tanks; a re-activation tank; two final sedimentation tanks; a separate sludge-digestion tank; eight open sludge drying beds; and a chemical dosing basin.

Grit Chambers.—There are three grit chambers; one square tank (18 ft. square by 4 ft. effective depth) is for dry weather flow, and the other two rectangular tanks, each 30 ft. long by 21.6 ft. wide by 5.45 ft. deep, are for storm flow.

On account of the great fluctuation between dry-weather and storm flow, the overflow weirs, which immediately precede the plant, separate a flow above three times of the dry weather flow and bypass it to the storm-flow grit chambers.

A bar screen of one-inch clear opening, equipped with a Dorr automatic cleaning mechanism, is provided for the dry-weather flow grit chamber.

Bar screens, with 2-inch clear openings and manual cleaning, are provided for the storm flow.

The dry-weather flow grit chamber is provided with a Dorr detritor.

Pump House.—The pump house is a reinforced-concrete building of 4970 sq. ft., in which the pumps, compressors, automatic water level recorders, Venturi meter for dry-weather flow, and other electric devices are located, together with a 5-ton movable crane.

Primary Sedimentation Tanks.—Each of the two Dorr clarifiers is 61 ft. square with an effective depth of 8.1 feet, with a conical bottom slope of 1 to 12.

One of them is used continuously and the other is provided for storm flow. The detention period for dry weather flow is 1.5 hours. The inlet and outlet weirs extend the entire length of the tank; they are

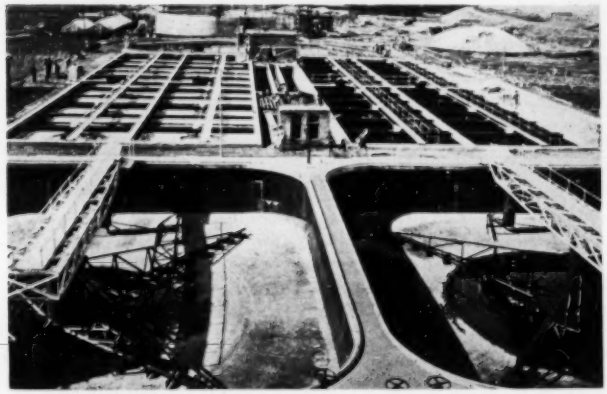

FIG. 1.—Toyohashi activated sludge plant under construction.

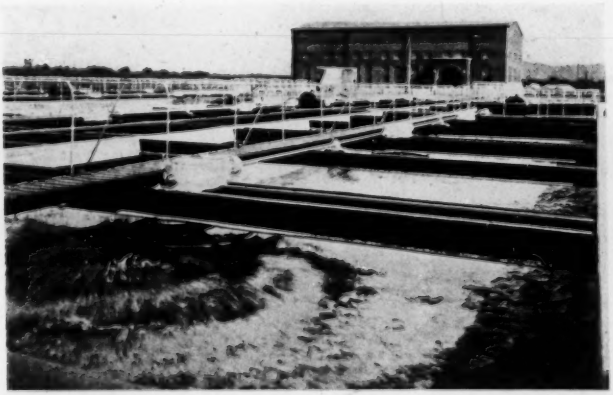

FIG. 2.—Simplex aerators, placed in operation, April 1, 1935. Toyohashi, Japan.

adjustable so that the disirable hydraulic conditions of flow can be obtained.

Aeration Tanks.—There are 24 aeration-tank units of the Simplex type, each 24 ft. square by 16.6 ft. deep. The 24 tanks are divided into 4 rows, each of 6 tanks.

The return sludge is 20 per cent of the sewage flow and the aeration period is 6 hours.

Reactivation Tank.—The reactivation tank is 66 ft. long by 5.3 ft. wide by 10 ft. deep.

The returned sludge is aerated by compressed air through 160 diffuser plates, each 1.05 ft. square by 1⅛ in. thick.

Final Sedimentation Tanks.—There are two final sedimentation tanks of the Dorr type, each 61 ft. square by 8 ft. effective depth. The detention period is 2 hours.

The effluent discharges into the Toyo River.

Separate Sludge Digestion Tank.—The capacity of the separate sludge digestion tank is about 106,000 cu. ft.; the tank is 73 ft. in diameter by 27.2 ft. deep.

The tank is covered and is equipped with the Dorr digestor mechanism.

The inside temperature of the tank is controlled so that the optimum temperature for digestion, about 80° F., is constantly maintained by the hot water coils, whose heat energy is supplied by the sewage gas generated in the tank.

Sludge Beds.—There are eight sludge-drying beds, each 46.5 ft. long by 15 ft. wide. The dosing depth of sludge is designed as 20 inches.

Chemical Dosing Tank.—The chemical dosing tank is used only in emergency cases such as when the chlorination of effluent may be forced by an epidemic. The tank is rectangular, 45 ft. long by 26.6 ft. wide by 4.7 ft. effective depth.

Construction Cost.—The total construction costs for the plant, including all necessary items (together with the land) was 595,100 yens (the Japanese yen is worth about 29 cents, U. S., at the present exchange rate).

Fujio Kashihara
University of Illinois,
Urbana, Illinois

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Verlag Chemie, G.m.b.h., Berlin W 35

This eighth volume of the well-known "Vom Wasser" series includes the papers presented at the Cologne meeting of the German Chemical Society in 1934. All of the papers in Part II, and some in Part I deal with water and its treatment. There are, however, 10 papers on sewage and industrial wastes, included from pages 49 to 168 in Part I. These 10 papers are as follows:

Inspection of the Sewage Treatment Works at Troisdorf. By H. Stoof (*Landesanstalt*, Berlin-Dahlem). This plant is built to handle the sewage and wastes from a large explosives factory. This sewage plant consists of two Travis tanks, containing wood "colloiders" in the upper story, separate sludge digestion tanks, unheated, and sludge drying beds. The plant was designed to treat a flow of 1,300,000 gallons in a 14-hour day. Operation has been checked occasionally since 1917 by the *Landesanstalt*. Twelve sets of samples between 1923 and 1933 showed an average of 471 p.p.m. suspended solids in the raw sewage and 48 p.p.m. in the effluent; the reduction of total nitrogen was low, from 18 p.p.m. in the raw to 14 in the effluent; also the reduction of permanganate oxygen consumed was low, from 62 to 56 p.p.m. The excellent removal of suspended solids is considered to be due to the Travis colloider. Sludge has been well digested and dries readily. Some of it has been dried, mixed with peat, and sold as a fertilizer.

The Discharge of Sewage Into the Sea. By C. Barenfanger. (Kiel.) The discharge of sewage effluents into sea water introduces different problems from those encountered with dilution in fresh water. The salt content, presence of different flora and fauna and effects of tides must be considered. Simple clarification often is insufficient, especially if the effluent cannot be diffused through multiple outlets.

Utilization of Wastes. By F. Sierp. (Ruhrverband.) Many industrial wastes contain values that must be determined and, if possible, recovered by efforts of the sewage chemists. Sewage effluents in themselves are of value, mainly for the water content. Organic wastes, such as those from paper factories, sugar factories, breweries and yeast plants,

should be treated to produce a satisfactory effluent, with little hope of recovery of valuable products. Organic sludges should, however, be utilized as fertilizers.

New Processes and Possibilities for the Chemical Treatment of Sewage. By H. Jung. (Niersverband.) Investigations of electrical and chemical processes have been made by the Niersverband. The first work was done in a 15-liter glass tank and later in a wooden tank of several cubic metres capacity. Ferric hydroxide was produced by electrolytic action from iron plates. It is claimed that 50 mg. per liter of iron from this source is equivalent to 60 mg. per liter as ferric chloride, and that the cost is only one-sixth as great. The current consumption of 570 kwhr. per million gallons, it is claimed, could usually be supplied by power from utilization of sludge gas. However, the process was considered to be unsatisfactory for further development, consequently another chemical process, utilizing iron as a precipitant, was investigated. Iron turnings were attacked with CO_2 and the ferrous bicarbonate formed in the sewage was oxidized to ferric hydroxide by aeration. Sludge gas can be used as a source of CO_2, although somewhat slow in action and insufficient in amount so that approximately 150 p.p.m. CO_2 must be supplied by combustion of coke.

Chemical treatment is recommended as combined with final biological treatment. The combined treatment gave 80 to 90 per cent reduction of permanganate oxygen consumed, whereas biological treatment gave only 75 per cent reduction.

Dr. Bach, in discussion, doubts the economic value of the process described by Jung and questions the efficacy of all chemical processes as contrasted with biologic.

The Biological Decomposition of Phenol. By F. Sierp and F. Fransemeier. (Ruhrverband.) Phenol in sewage is decomposed mainly by biological action. End products are water and CO_2, and oxygen is required in proportion to the CO_2 produced. The 5-day B.O.D. is 1.9 mg. per l. per 1.0 mg. per l. phenol, the 20-day 2.3 mg. per l. The destruction of phenol is accelerated by the presence of organic matter, ammonia or phosphate. Temperature increase also greatly increases the rate of decomposition, while the rate is very slow below 7° C.

Determination of Phenol. By R. Czensny. (Berlin.) The Folin-Dennis method has been modified in various ways, but a simpler method is desirable. The Hilpert p-nitranilin method has been used with success. A m-nitranilin solution is preferable for cresols or mixed phenols. A method is given for determination of phenols in fish.

Estimation of Phenol in Water and Sewage. By F. Meinck and M. Horn. (Berlin.) Determination of phenol by bromination methods is not accurate due to side reactions, and factors must be used to estimate

results. The distillation procedure gives quite variable yields. For small amounts of phenol, several colorimetric methods are available but all are subject to production of off-color solutions, not comparable with standards.

(A good bibliography is included.)

Experiments on the Treatment of Industrial Wastes by Activated Sludge. By E. Nolte, H. J. Meyer and E. Fromke. (Magdeburg.) Experiments were conducted in an experimental mechanical aerator of the Haworth paddle-wheel type, with a capacity of 70 litres. Beet sugar wastes were studied at Salzwedel. Wastes containing up to 1000 mg./l. butyric acid could be treated in 8 hours of aeration. Later, in tests at Magdeburg, pure butyric acid was oxidized, after addition of limestone, ammonium carbonate and ammonium phosphate. Sugar, cresol and various wastes were treated successfully when nitrogen and phosphorus compounds were added. These compounds may make feasible the treatment by activated sludge of industrial wastes otherwise quite difficult to treat by this process.

Treatment of Wastes from Starch Factories. By W. Husmann. (Zurich.) Separation of condenser water and concentrated wastes is essential. Condenser waters can be discharged untreated. Wash water from potatoes can be settled and discharged. Concentrated steep-water must be treated biologically. Treatment of wastes combined with sewage is most successful. (Bibliography of 35 references.)

Copper-bearing Wastes: Their Detection and Influence in Streams. By R. Czensny. (Berlin.) Copper in sewage at New Haven was shown to be very toxic to bacteria. Fish are killed by 5 mg./l. copper sulphate, and Ebeling reports 0.5 mg./l. toxic to brook trout. If algae, duckweed, etc. are present, fish will survive larger amounts of copper than in clear water, since the copper will be stored in the plants. For determination of copper, the colorimetric method of Spaku is recommended. The sample, concentrated if necessary, is treated with solutions of ammonium thiocyanate, pyridine and 0.5 c.c. chloroform. The green color extracted by the chloroform is compared with standards. The method can also be used for copper in plants, fish and sludge.

The papers dealing with water in Parts I and II are abstracted in the Journal of the American Water Works Association, August, 1935, pages 1093 to 1099.

F. W. Mohlman

REPORT ON GREATER LONDON DRAINAGE

By J. R. Taylor,* Sir George W. Humphreys † and T. Peirson Frank ‡

Americans accustomed to superlatives in cost and size of engineering projects will open their eyes in surprise upon reading this report of a colossal scheme for disposing of the sewage of Greater London. The recommended project comprises an area of 1,928 square miles, a population of 9,237,000 in 1931 and an estimated ultimate population of approximately 20 millions, and a cost of £ 50 million for the construction of sewers and treatment works.

The report consists of 116 pages, in a bound volume 9 by 13 inches, with four diagrams and five plans showing the areas and schemes involved. The Ministry of Health and the London County Council collaborated in the preparation of the report, the former being represented by Mr. J. R. Taylor, and the latter by Sir George W. Humphreys until his retirement in 1930, followed by the appointment of Mr. T. Peirson Frank.

The engineering board considered two main schemes, as follows:

I. To treat the sewage of Greater London
   at (*a*) Twenty-three sewage disposal works,
   at (*b*) Ten sewage disposal works.
II. To discharge such sewage into the sea.

The London County Council now operates two large clarification plants, at Barking (North) and Crossness (South) on the Thames 11 and 13 miles, respectively, below London Bridge. The Council owns 332 and 562 acres, respectively, at the two sites. A population of 3,596,313 was tributary to Barking, and 1,961,956 to Crossness, in 1931. The daily average sewage flow in 1931–32 was 186.3 million Imp. gallons to Barking and 102.8 millions to Crossness, equivalent to 51.8 and 52.4 Imp. gal. per cap. per day.

Outside the County of London there are 182 sewage treatment works in the area covered by this report.

In Scheme I (*a*), these 184 works would be combined by intercepting sewers, according to areas shown in maps in the Report, into 23 major works. This number of 23 still appears too many to the Commission, consequently Scheme I (*a*) was not given further consideration.

In Scheme I (*b*), the present works would be combined, and the entire 1,928 square miles provided with intercepting sewers to carry the flow to 10 sewage treatment works, which would include the Barking and

* *Engineering Inspector, Ministry of Health,* † *Late Chief Engineer, London County Council, and* ‡ *Chief Engineer, London County Council.* H. M. Stationery Office, Adastral House, Kingsbury, London, W. C. 2. Price, 17 s. 6 d. 1935.

Crossness plants, the West Kent Main Sewerage Project, and the West Middlesex Project. (The West Middlesex Project was described in This Journal, November, 1933, page 1054. Construction of the sewers and treatment works is approaching completion, under the engineering direction of Mr. John D. Watson.)

The ten treatment works and system of sewers considered under Project I (*b*) are estimated to cost, in three installments, £ 28, 13.5 and 8.5 millions, or a total of £ 50 millions. The type of treatment works is not specified in the report, but the cost of operation is taken as the average for present costs, which apply mainly to clarification works. The costs of operation at Barking and Crossness in 1931–32 totaled £ 498,365, or 1s. 9½d. per capita; costs for outlying plants varied from 2s. 2d. to 3s. 4d. per capita. The operating cost for Scheme I (*b*) is estimated at 2s. per capita.

Scheme II comprised collection of all of the sewage of the area involved, construction of pumping stations, tunneling from 100 to 500 ft. below the surface for a distance of 63 miles to the English Channel at Dungeness and discharge into sea water 90 ft. deep at a point where currents through the Straits of Dover might be depended upon to disperse and disintegrate sewage solids. If settling or screening proved necessary, the marshy and sparsely populated shores would be available for such plants.

This scheme was estimated to cost £ 110 millions, in three installments of £ 62, 25 and 23 millions. The annual cost of operation was estimated at 1s. 6d. per head.

In view of the far greater initial installment required for the outfall sewer, and possible unforeseen difficulties in a project of such magnitude, the Board has recommended Scheme I (*b*), involving the construction of sewers and 10 treatment plants, at an initial cost of £ 28 millions.

It is apparent that this project is as yet on paper, but the value of the report as a fundamental basis for the future drainage and sewage disposal of greater London cannot be overestimated.

The appendices to the report are voluminous, covering pages 45 to 116. They give detailed information concerning the populations and methods of treatment at the present sewage disposal works.

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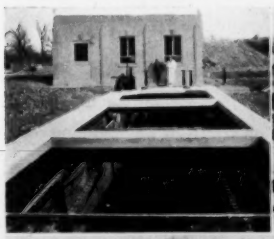

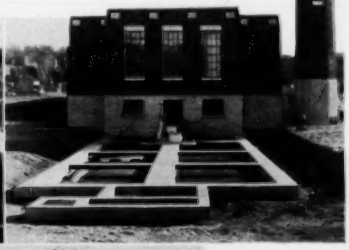

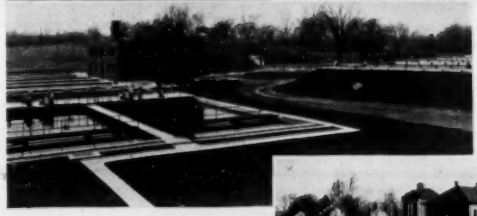

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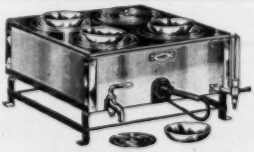

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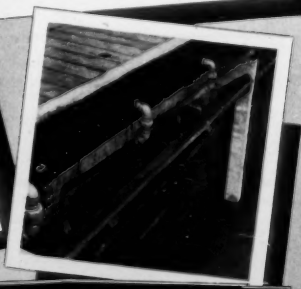

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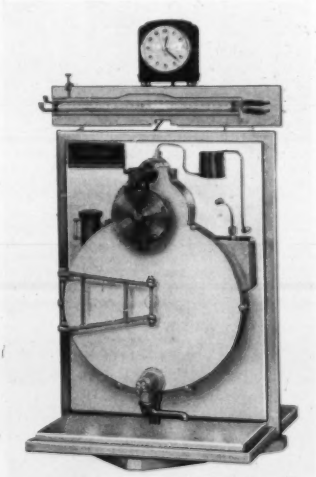

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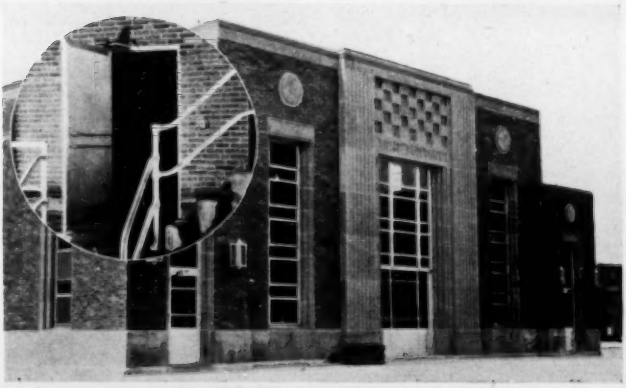

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